ITK-SNAP Training Course at NCI

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Course Aims

- Review basic image segmentation theory
- Demonstrate main ITK-SNAP features
  - Image viewing and navigation
  - Manual segmentation
  - Automatic segmentation
- Practice using hands-on exercises

About Me

- Assistant Professor of Radiology at Penn
- Research interests:
  - MRI segmentation, morphometry
    - Neuroimaging biomarkers for AD
    - Hippocampus
    - Mostly brain, some cardiac MRI
- Lead developer of ITK-SNAP from 2003

About ITK-SNAP

- Launched by Guido Gerig (UNC, Utah) in late 90s as a series of student projects
- From the beginning, meant to be accessible to clinical users
- Continued development funded by NLM in 2004, NIBIB in 2007-9.

Course Modules

- Module 1: Introduction
- Module 2: Image Viewing and Navigation
- Module 3: Manual Segmentation
- Module 4: Automatic Segmentation
- Module 5: Advanced Topics

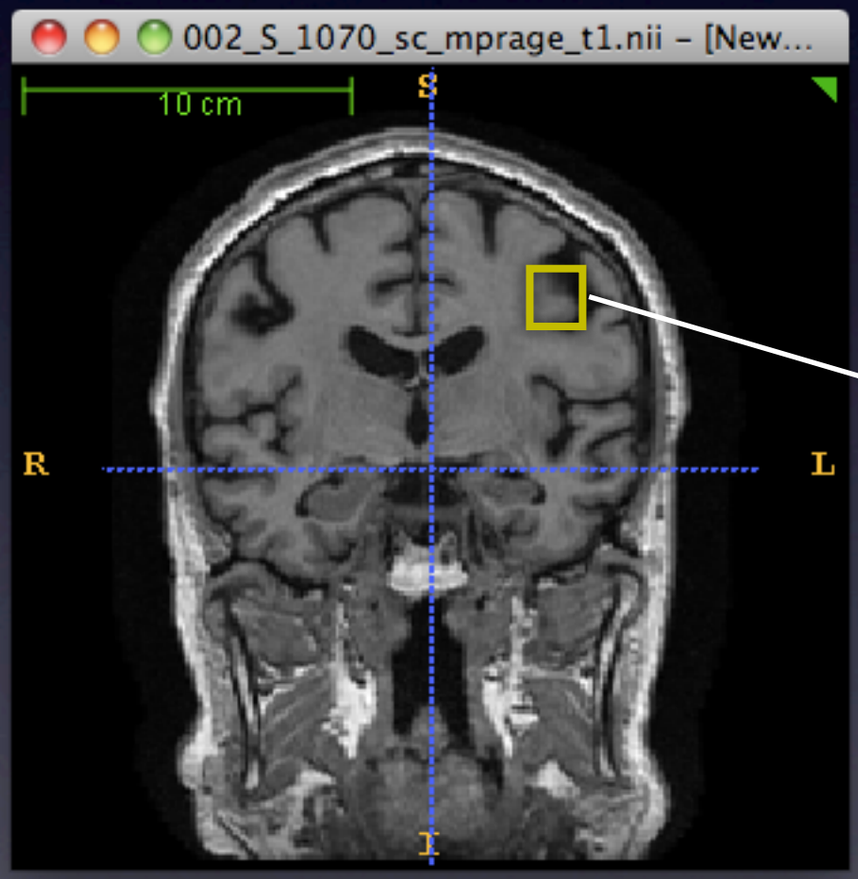
Module 1. Introduction

- Review of basic imaging concepts
- Where to get help?

What is a 3D Image?

- A set of physical measurements organized in space and time
- Organization is highly regular:
  - A rectangular grid of measurements
  - A cone of measurements

Images as Arrays of Volume Elements (Voxels)



12	31	224	...
234	123	434	...
234	453	23	...
...	...	...	...

Image Intensity

Properties of a Voxel

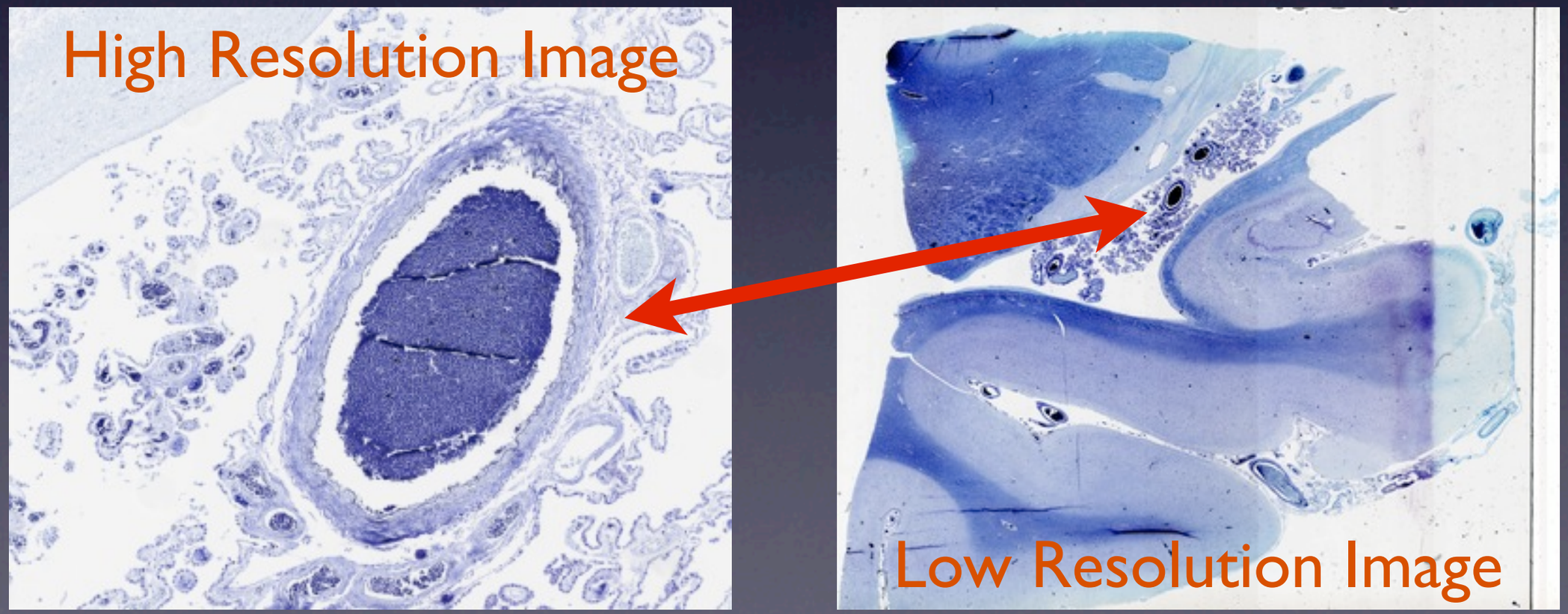
- **Intensity**:
  value of the voxel
- **Dimensions**:
  size of the voxel in (mm^3)
- **Physical coordinates**:
  position of voxel in a scanner-based coordinate system
- **Image coordinates**:
  column, row, slice of the voxel in the image volume

3D Image Properties

- Spatial Resolution
- Spectral Resolution
- Signal, Noise, Contrast
- Spatial Orientation

Spatial Resolution

- Number of voxels per unit of distance
- Low resolution: can't *resolve* nearby objects

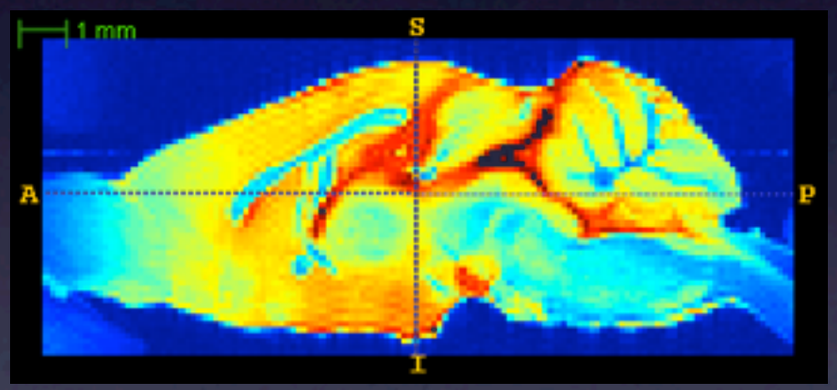


Isotropic vs. Anisotropic

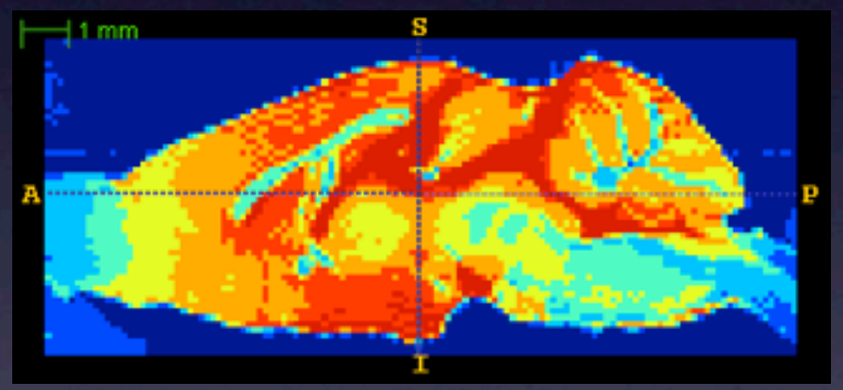
- Resolution may be different in each dimension of the image
- Isotropic image: all three dimensions of the voxel are the same
  - e.g., 0.8mm x 0.8mm x 0.8mm
- Anisotropic: dimensions of the voxel are different
  - e.g., 1.2mm x 1.2mm x 5mm

Spectral Resolution

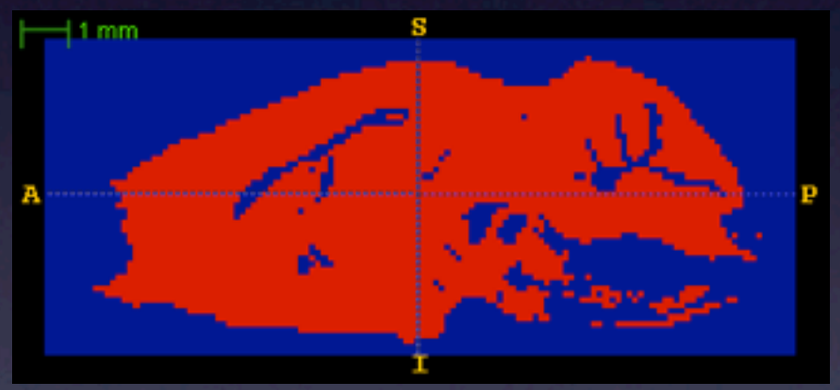
- Number of different intensity levels



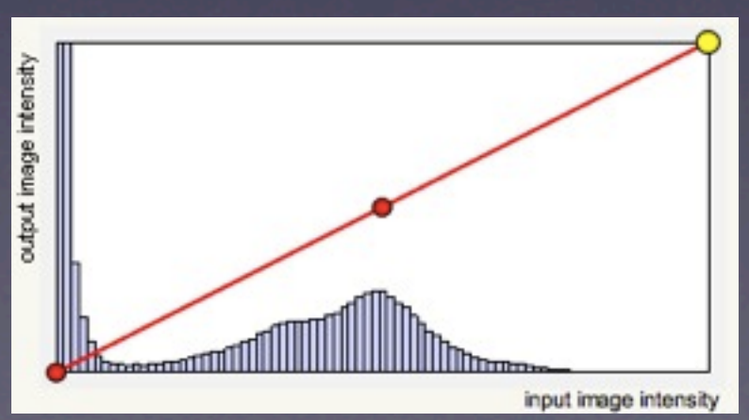
256 levels

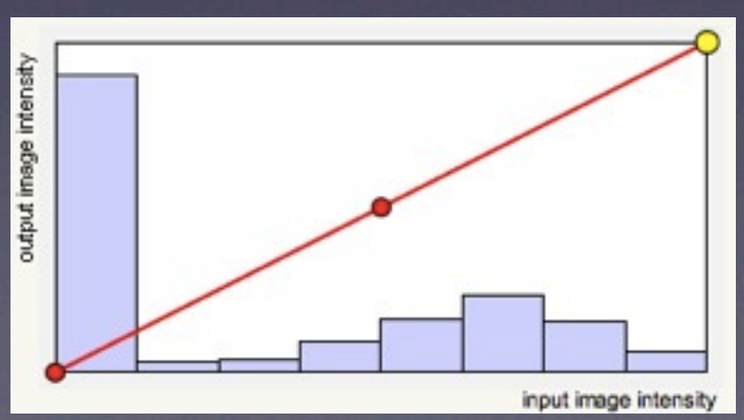


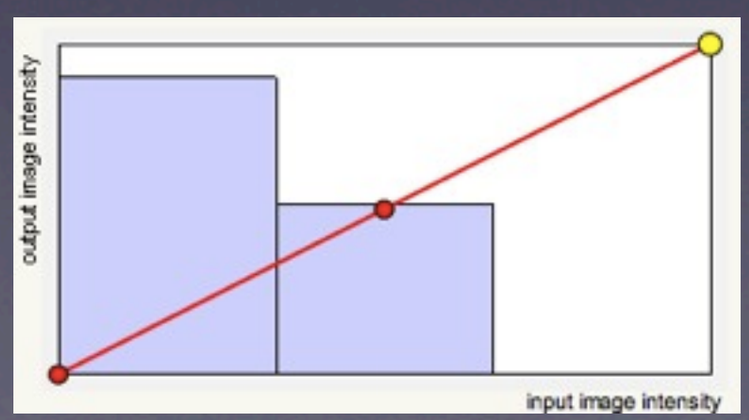
8 levels



2 levels



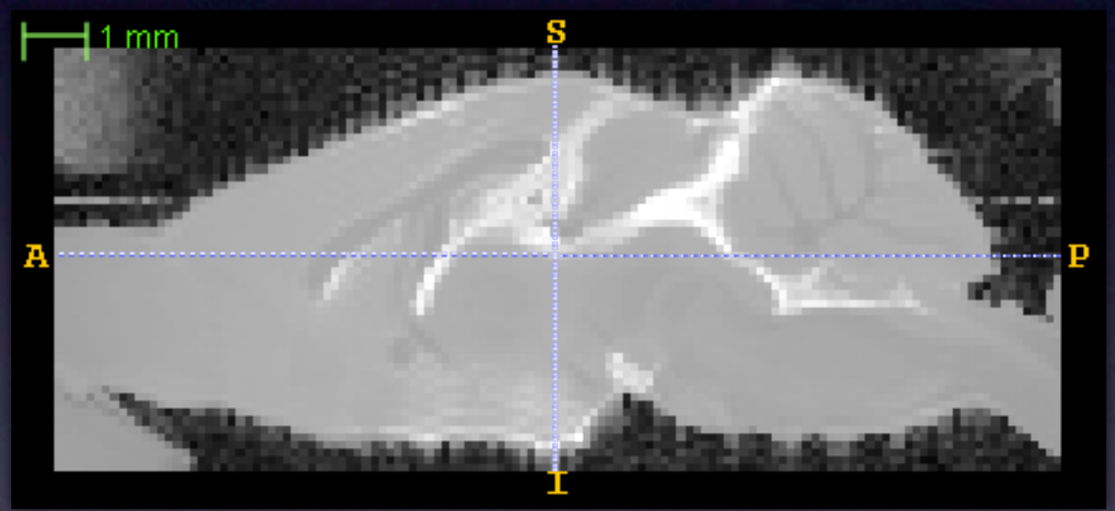


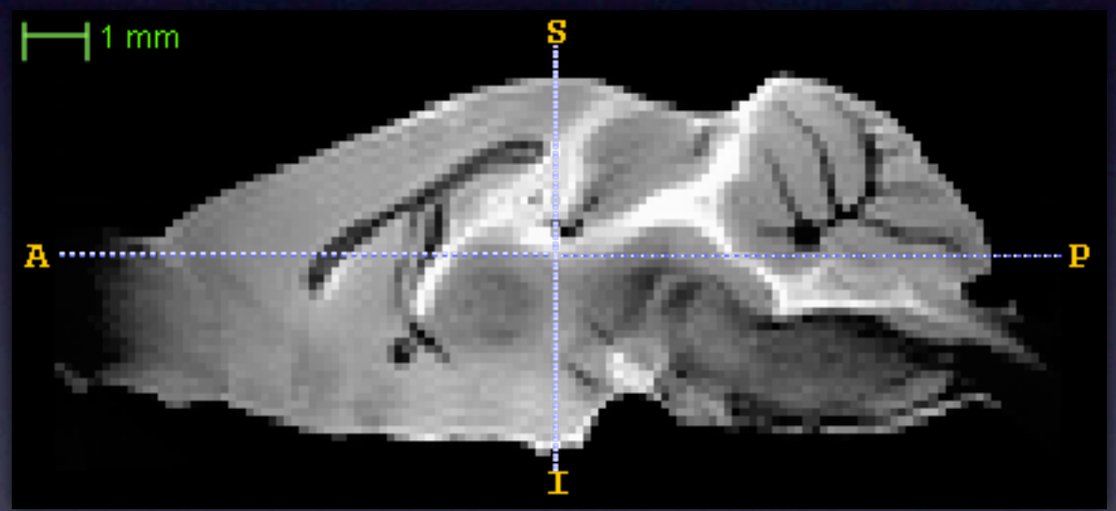


Signal, Noise, Contrast

- Signal
  - intensity due to sample
- Noise
  - intensity due to other sources, measurement errors, etc.
- Signal to Noise Ratio
  - higher values = better images
- Contrast
  - difference between intensity of relevant tissues, relative to noise

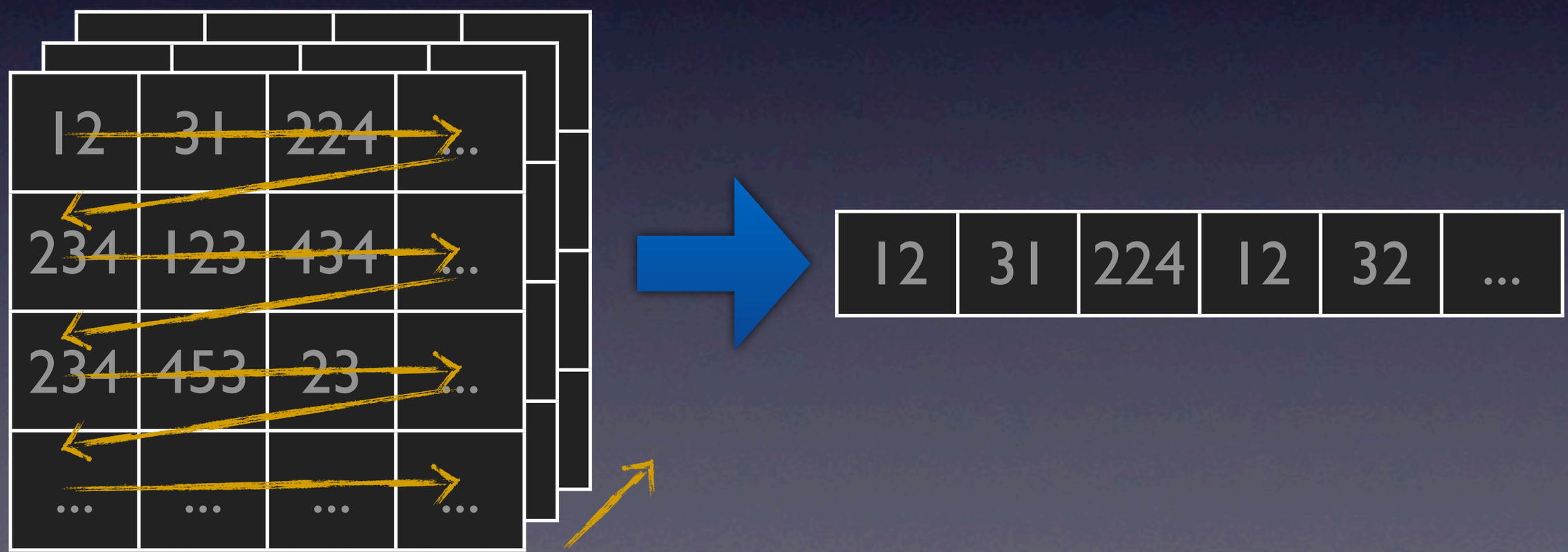
Low vs. High Contrast





Images in the Computer

- Image is encoded in disk/memory as a list of numbers

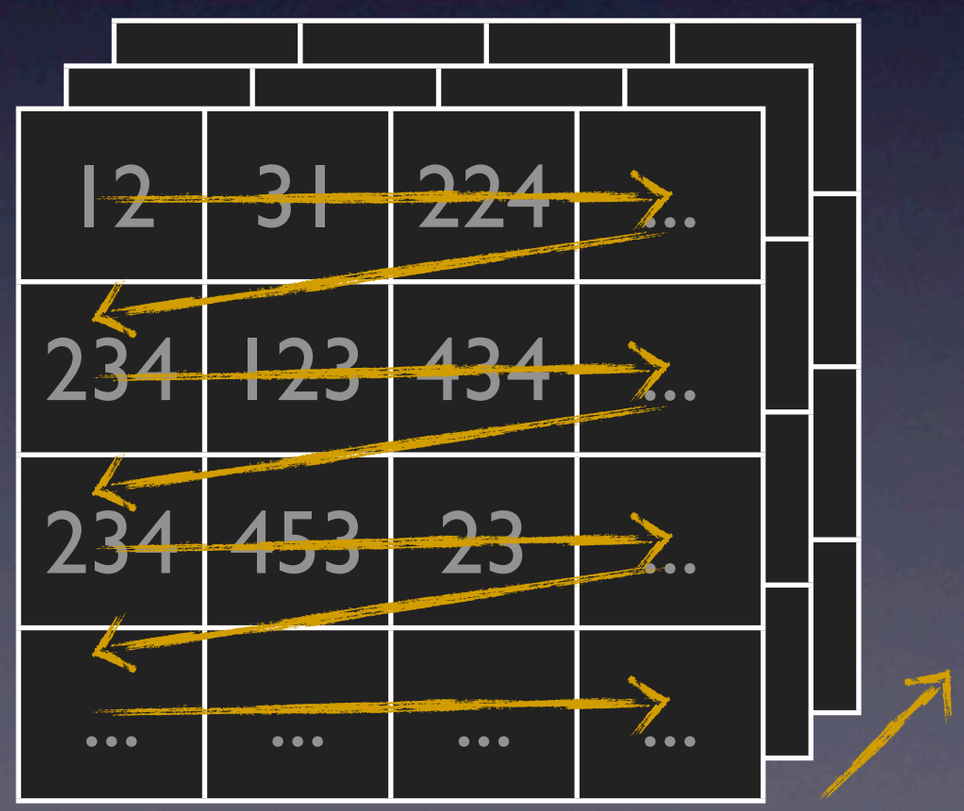


3D Image File Formats

- DICOM (.dcm/.0234123534):
  - Industry standard
  - Each 2D slice stored in a separate file
  - SNAP can read (usually)
    - if not, try **dcm2nii** from **MRIcron**
- NIFTI (.nii):
  - Widely used in image analysis field for MRI, CT, PET
  - Image stored as 3D (or 4D) volume
  - SNAP can read, write - along with most other tools
- Analyze (.hdr/.img)
  - Not recommended (superseded by NIFTI)

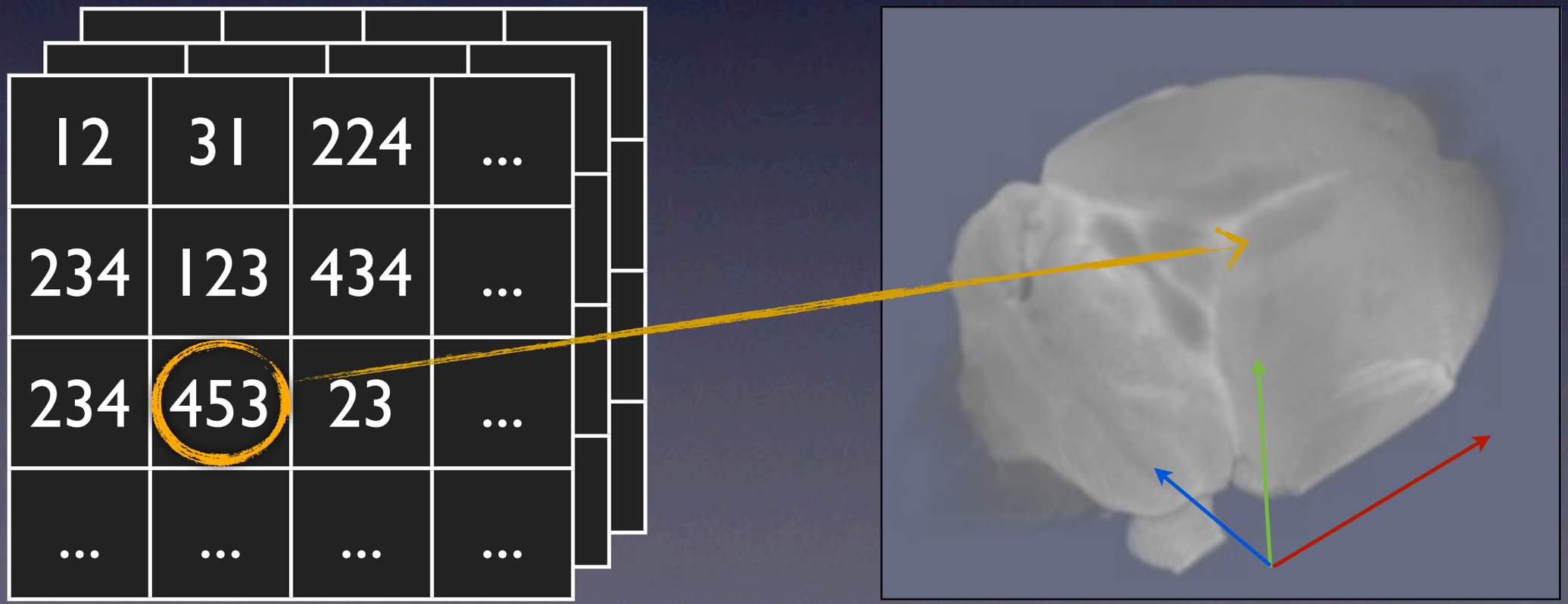
Spatial Orientation

- Each voxel has a coordinate in “image space”
  - x: column
  - y: row
  - z: slice



Spatial Orientation

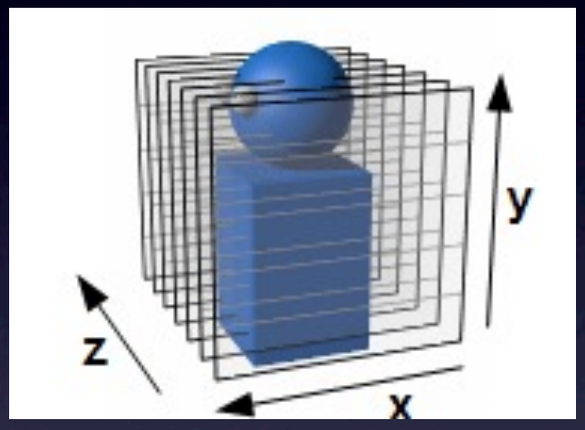
- But it also has a location in the physical space
  - (x,y,z) of the corresponding location in the scanner



Spatial Orientation

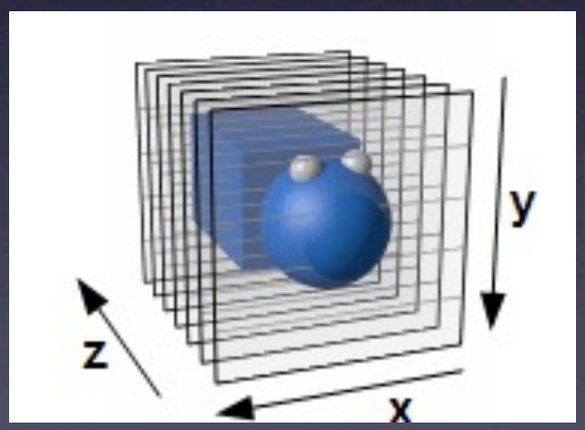
- Transformation from voxel coordinates to physical coordinates is typically linear, given by the form $y = Ax + b$
- In SNAP, we assume that coordinate axes in voxel space are parallel to the coordinate axes in physical space

Orientation in SNAP



Voxel Axis	FROM	TO
x	**p**osterior	anterior
y	**i**nferior	superior
z	**l**eft	right

PIL



Voxel Axis	FROM	TO
x	**r**ight	left
y	**a**nterior	posterior
z	**s**uperior	inferior

RAS

...

(48 different orientations)

Visualization of 3D Image Volumes

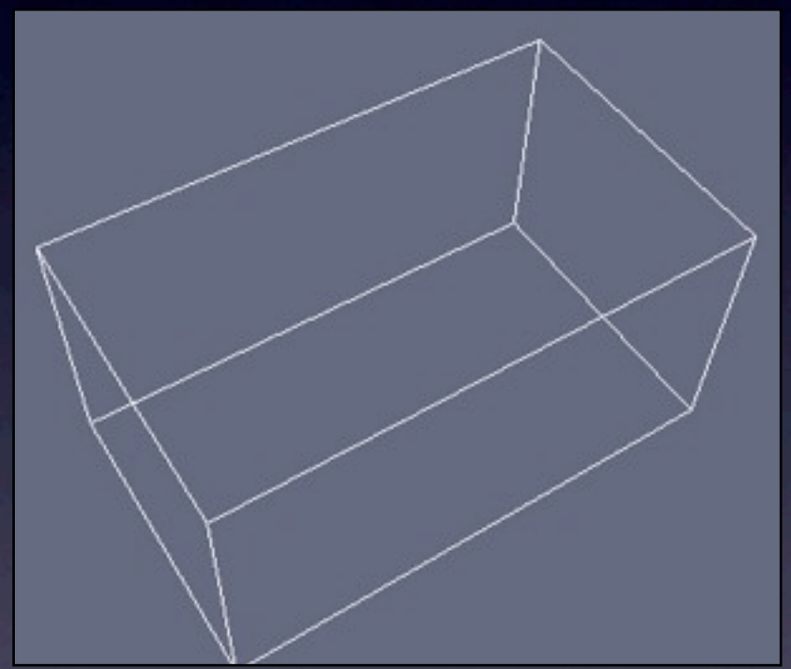
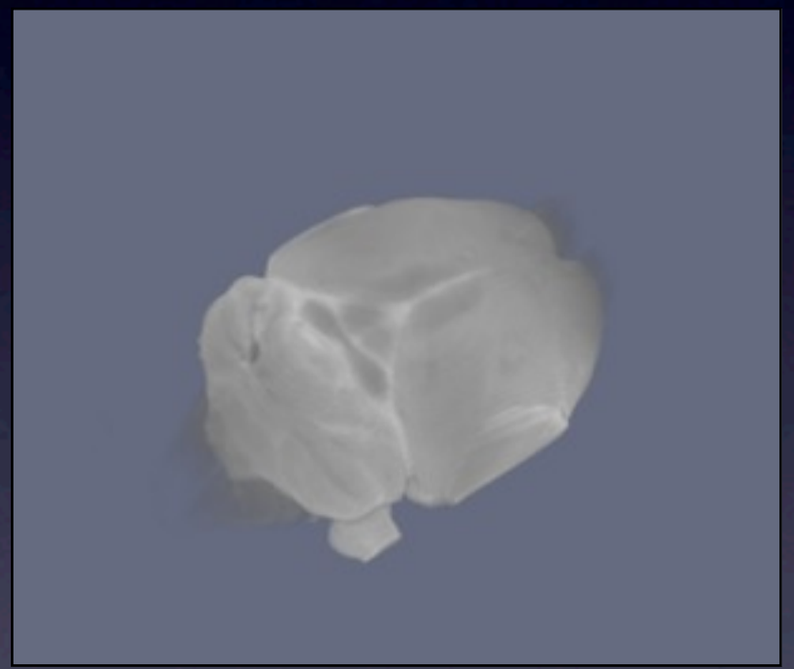
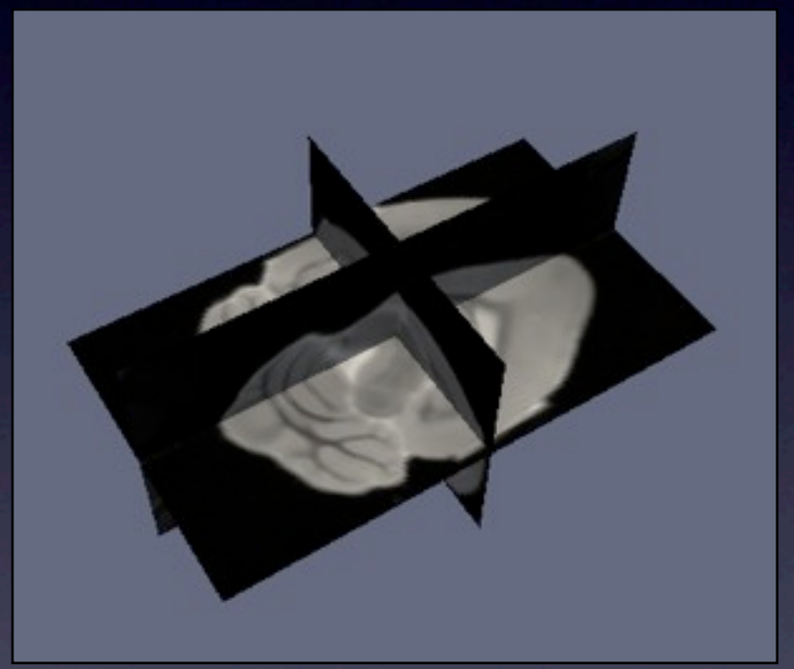


Image Volume

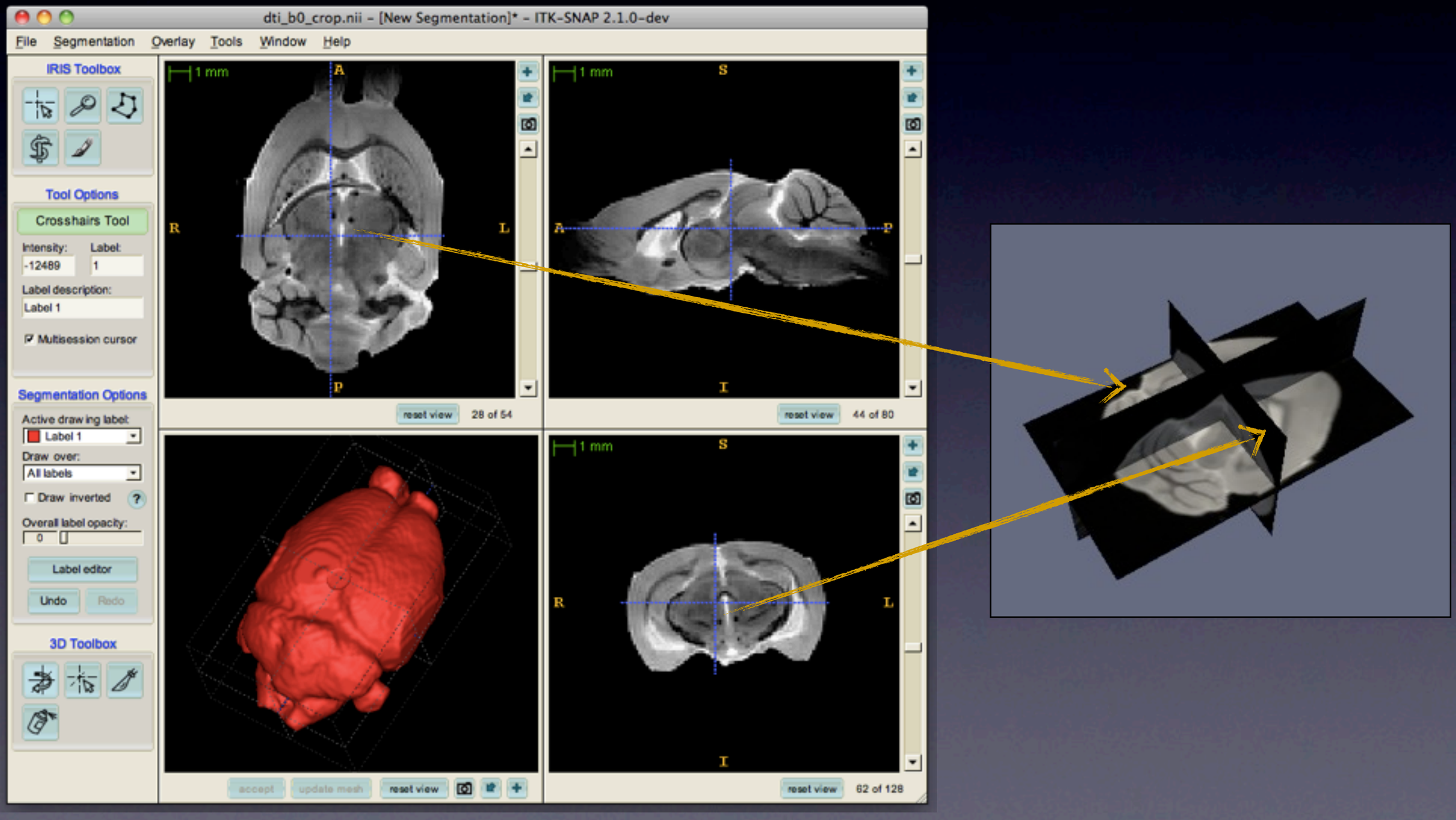


Volume Rendering



Orthogonal Slices

Visualization in SNAP



Review Questions

- How would we go about measuring SNR and contrast in a medical image?
- Can the spatial resolution of the image be changed? How? Is it a good idea?

Where to Go for Help?

- http://www.itksnap.org
  - Tutorials
  - Discussion list
  - Bug tracker
  - Technical documentation
  - Information on how to cite ITK-SNAP

Course Modules

- Module 1: Introduction
- Module 2: Image Viewing and Navigation
- Module 3: Manual Segmentation
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Module 2: Image Viewing and Navigation

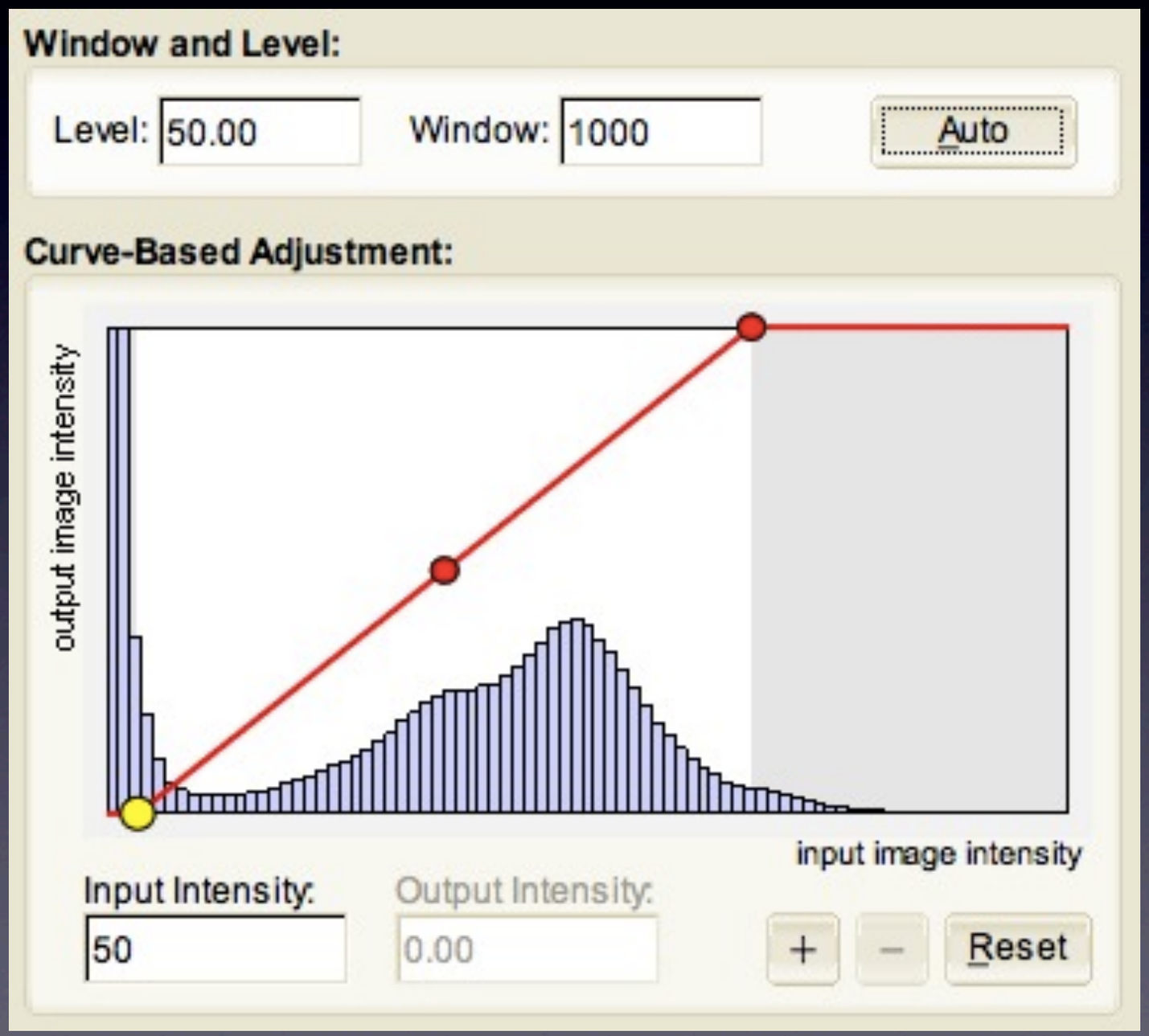
- Load images into SNAP
- Navigation
- Image Contrast Adjustment
- Image Information Console

GUI Demo

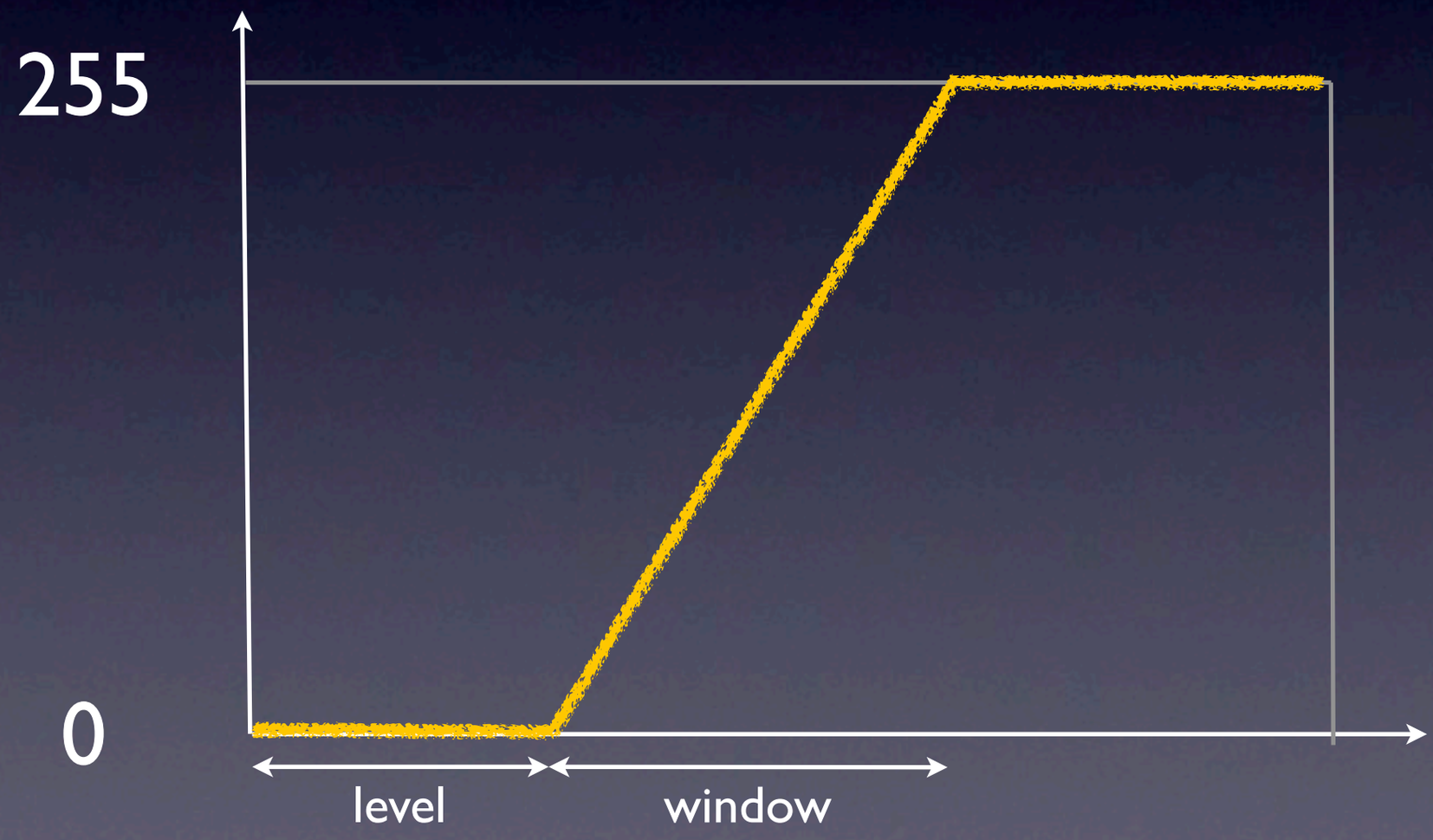
Image Contrast Dialog

- The screen can show 256 shades of gray
- Human eye has limited spectral resolution
- Often only a range of the image spectrum is interesting
- Image contrast dialog maps input image intensities into 256 shades of gray on the screen

Image Contrast Dialog

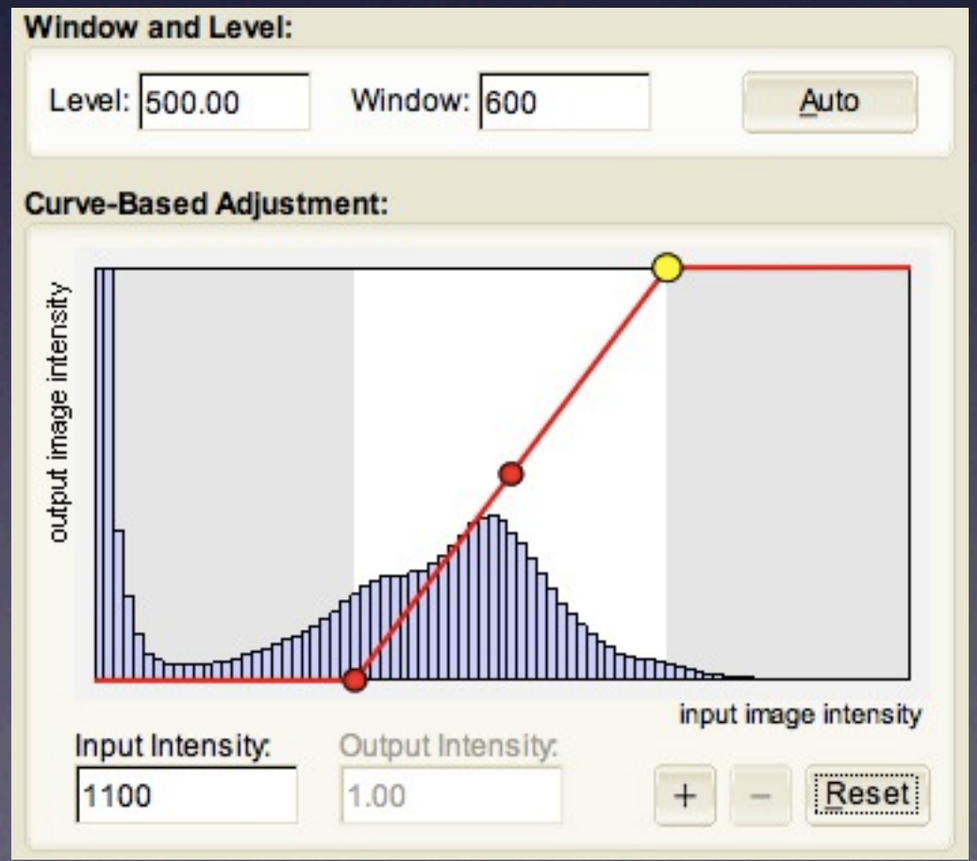


Window and Level

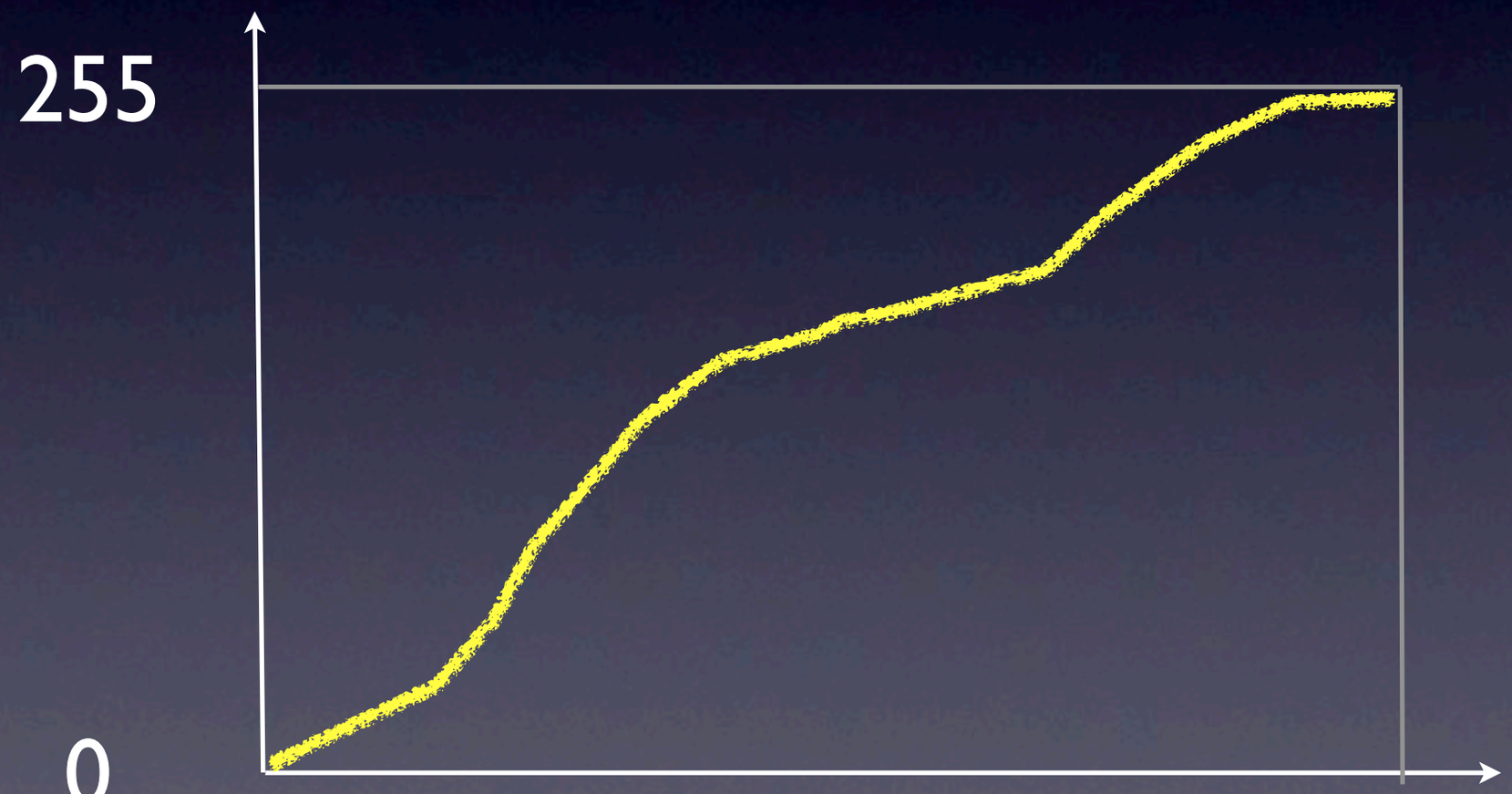


Window and Level

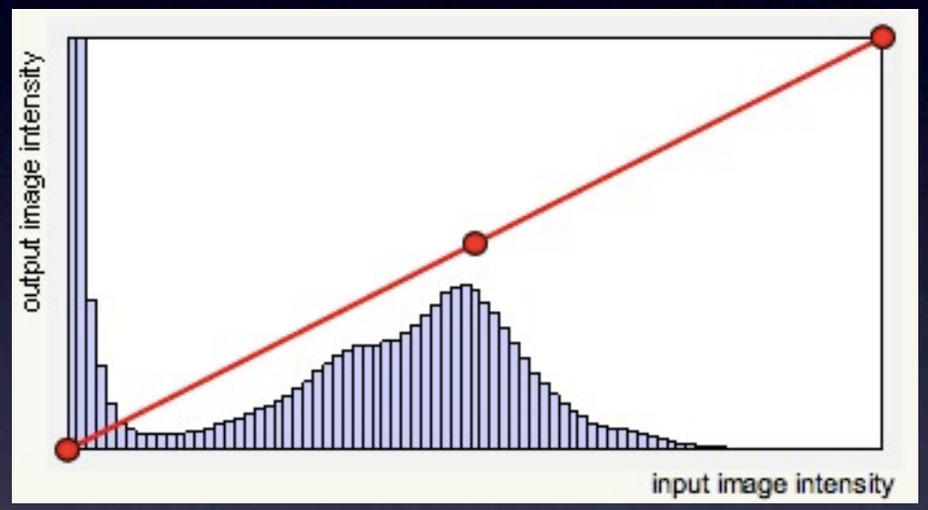
- Example: level=500, window=600
  - Intensities below 500 map to 0
  - Intensities from 500 to 1100 map linearly to range [0 255]
  - Intensities above 1100 map to 255

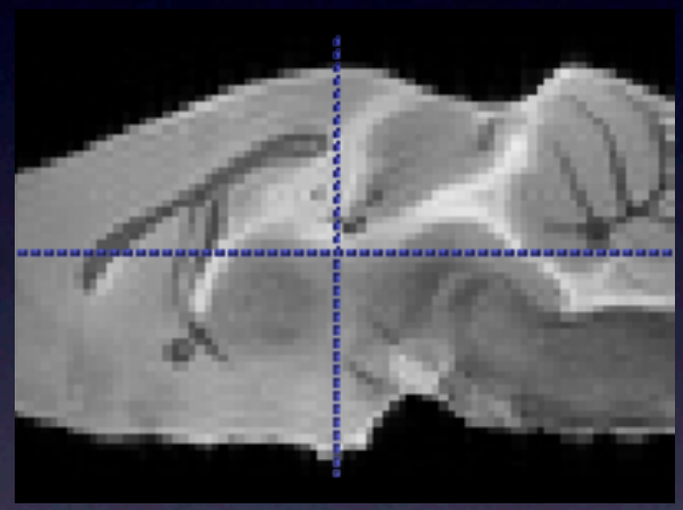


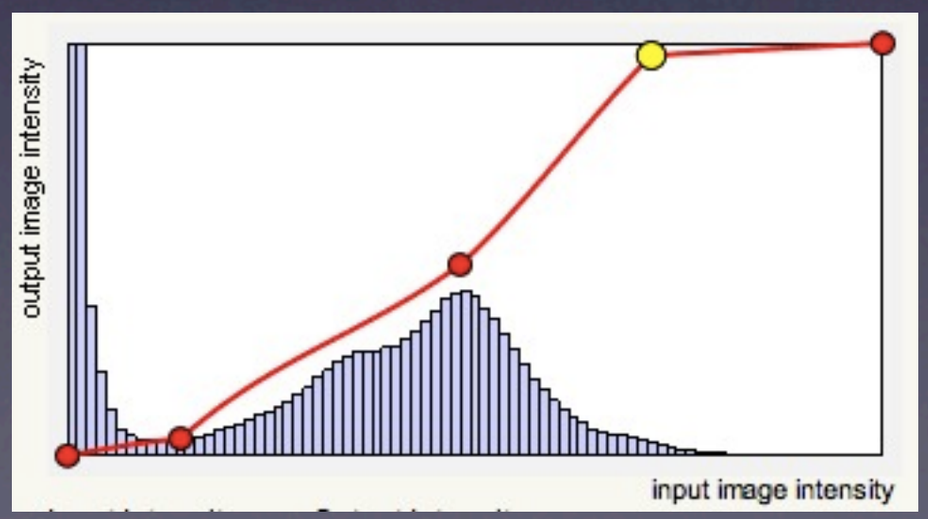
Fine-Scale Image Contrast Adjustment



Fine-Scale Image Contrast Adjustment







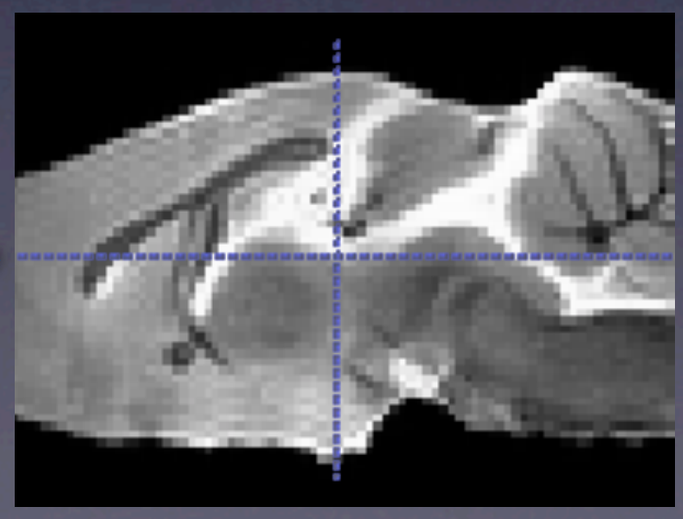


Image Information Page

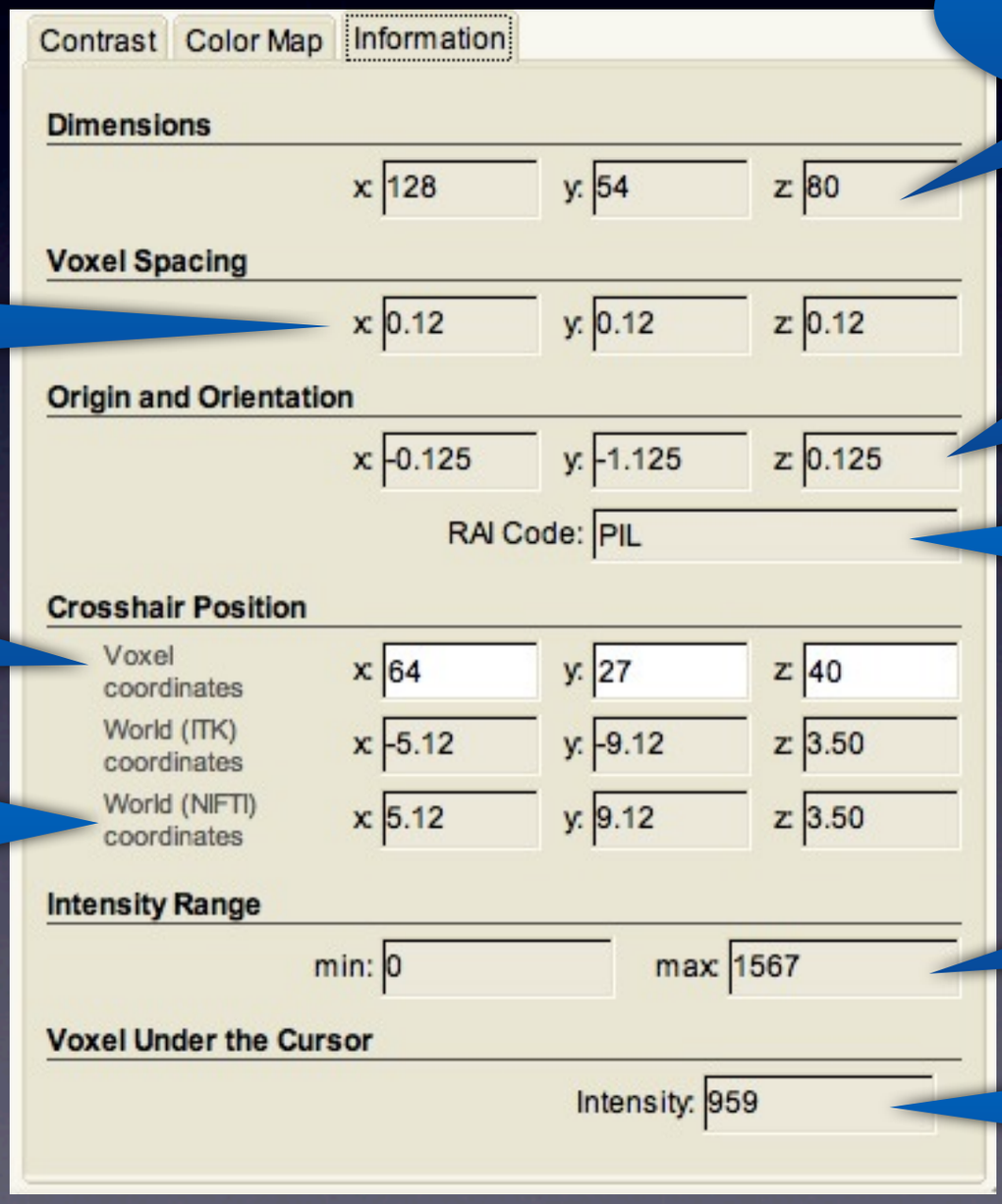


Image dimension in units of voxels

Voxel size in units of mm

Physical coordinate of voxel (0,0,0)

Voxel coordinates (column, row, slice) of the crosshairs

Describes how axes in voxel space (column, row, slice) map to physical x, y, z axes

Physical coordinate of the crosshairs in RAS space (x=R->L, y=A->P, z=S->I)

Minimum and maximum intensities in the image

Intensity of voxel under the cross-hairs

Hands-On Exercise (10 minutes)

1. Load NIFTI image *mouse_brain_t1.nii*
2. Adjust contrast using level & window controls
3. Guesstimate the intensity range of the cortex, ventricles, background by moving the crosshairs around the image
4. Use curve contrast control to maximize the contrast in the cortex
5. What are the physical coordinates of voxel (40,30,55)?
6. Save image in Analyze format (.hdr extension)

Course Modules

- Module 1: Introduction
- Module 2: Image Viewing and Navigation
- Module 3: Manual Segmentation
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Module 3: Manual Segmentation

- How segmentation is represented in SNAP
- Polygon tool
- Paintbrush tool
- 3D visualization and tools

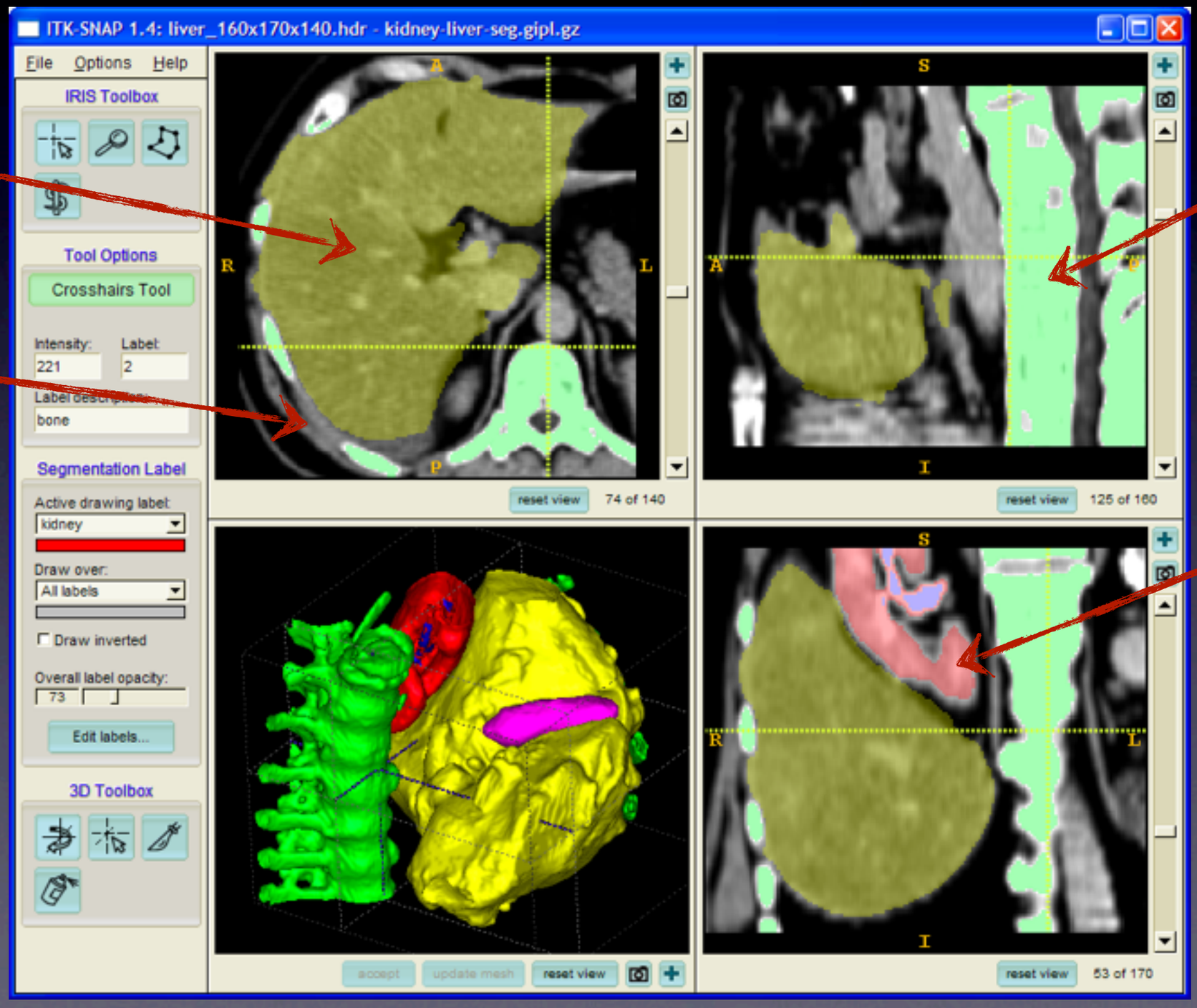
What's Segmentation?

- Delineation of structures of interest
- In SNAP, each voxel in the input image is assigned a unique *label*
- Labels are numbers from 0 to 255
- A segmentation, then, is just an image with 256 intensity levels

What's Segmentation?

5: liver

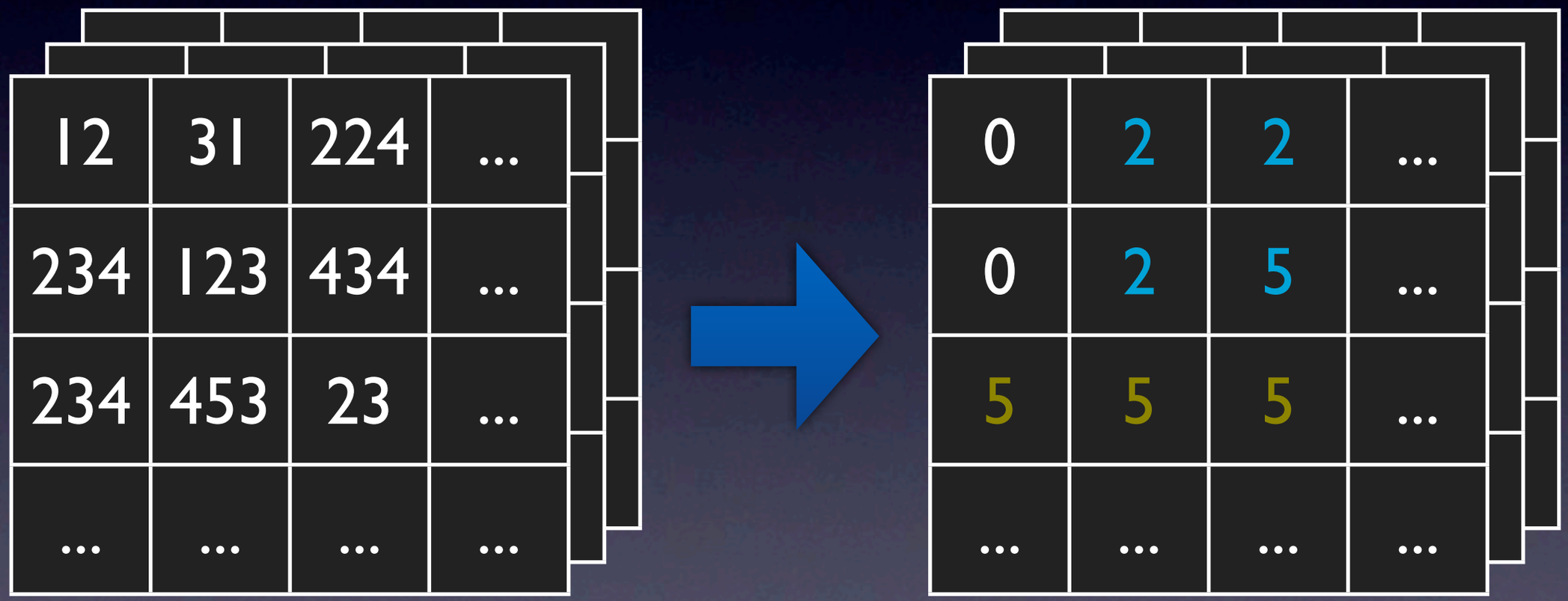
0:"clear" label



2: bone

1: kidney

What's Segmentation?



Drawing Operations

- Polygon Tool
  - Trace outlines of structures
- Paintbrush Tool
  - Touch up segmentations
- Other tools (later)

Drawing Operations

- Initially all voxels are assigned clear label (0)
- Drawing operation replace the existing label with the **active** label
- User can protect some existing labels by choosing **draw-over** labels

Draw-Over Label

Draw-Over	**Protection**
“All Labels”	No labels are “protected”
“Visible labels”	Labels tagged as “hidden” are protected
“Clear label”	Labels 1-255 are protected
“Label 2”, e.g.	All labels except 2 are protected

Properties of Segmentation Labels

- Name (e.g., "Hippocampus")
- Id (0-255)
- Display color
- Display opacity
- User can define and change these properties

GUI Demo:

Polygon Tool

GUI Demo:

Label Management

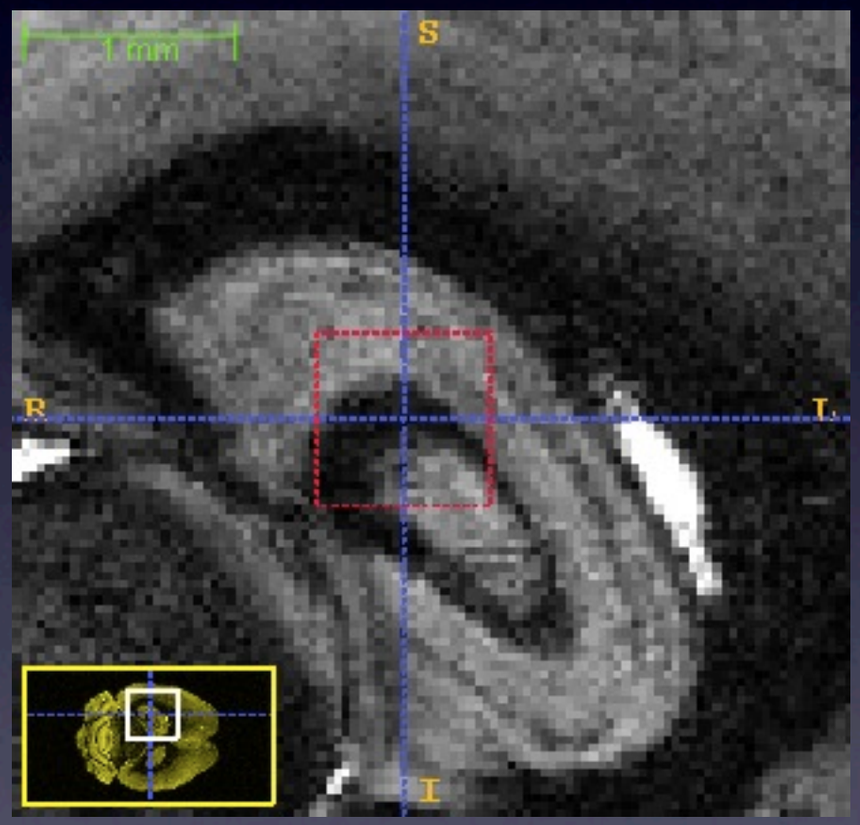
Paintbrush Tool

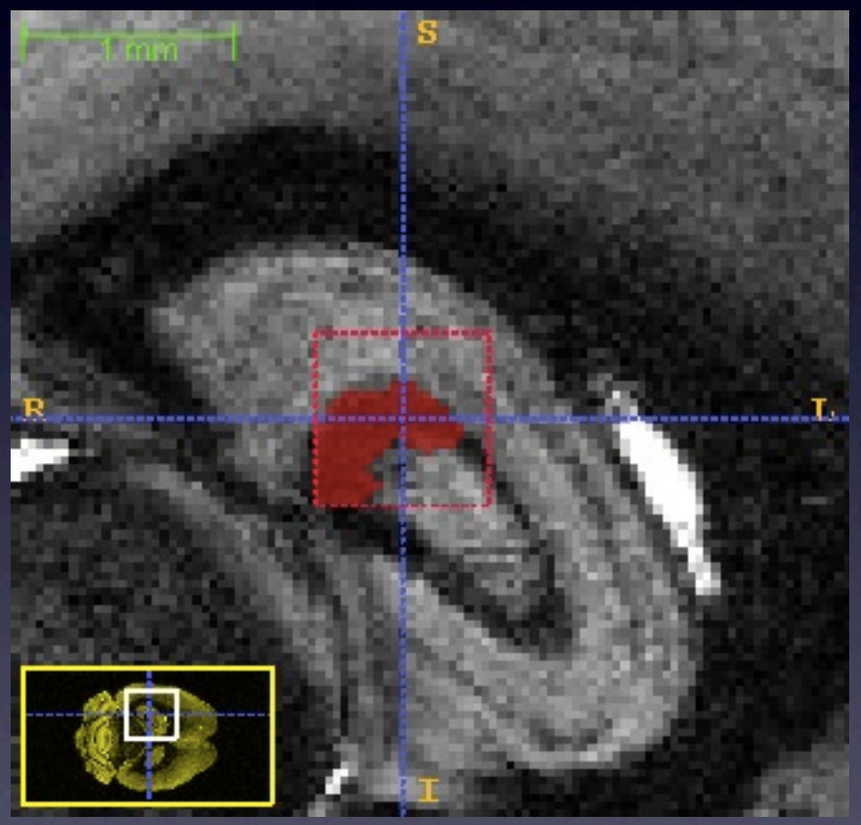
- Quick touch-up with brushes of different shapes and sizes
- Quickly switch between drawing and erasing with R/L mouse buttons
- Adaptive brush for semi-automatic segmentation

Adaptive Paintbrush

- Brush shape sets the boundary of the region where segmentation is performed
- Center of the brush is the reference voxel
- A contiguous set of voxels with intensity similar to the reference voxel is labeled
  - *Uses watershed algorithm*

Adaptive Paintbrush



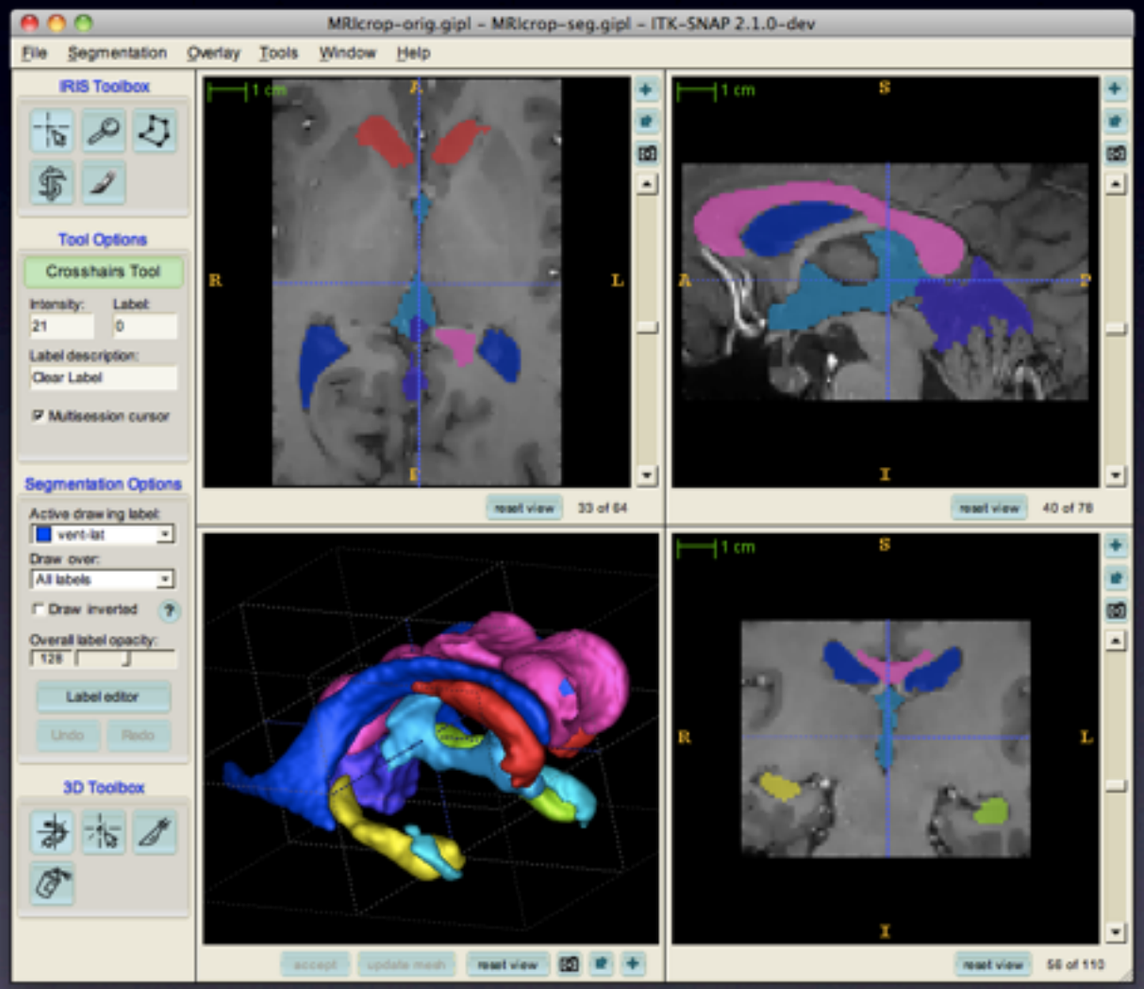


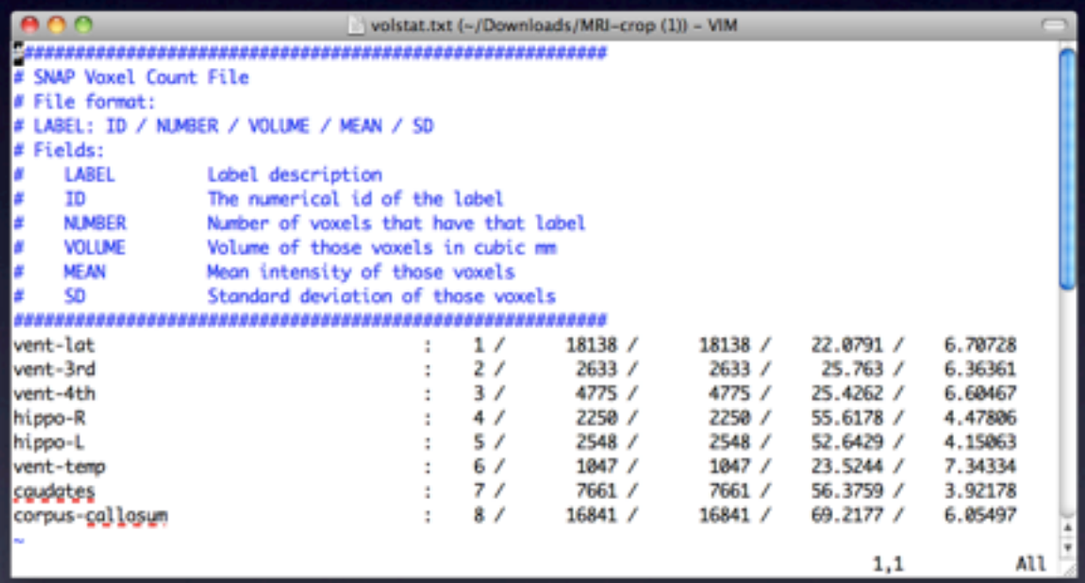
GUI Demo:

Paintbrush Tool

GUI Demo: Segmentation Files and 3D Visualization

Volumes and Statistics





Volumes and Statistics

volstat.txt (~/Downloads/MRI-crop (1)) - VIM

```
#######################################################################
# SNAP Voxel Count File
# File format:
# LABEL: ID / NUMBER / VOLUME / MEAN / SD
# Fields:
#    LABEL          Label description
#    ID             The numerical id of the label
#    NUMBER         Number of voxels that have that label
#    VOLUME         Volume of those voxels in cubic mm
#    MEAN           Mean intensity of those voxels
#    SD             Standard deviation of those voxels
#######################################################################
vent-lat                                  :    1 /      18138 /      18138 /    22.0791 /    6.70728
vent-3rd                                  :    2 /       2633 /       2633 /     25.763 /    6.36361
vent-4th                                  :    3 /       4775 /       4775 /    25.4262 /    6.60467
hippo-R                                   :    4 /       2250 /       2250 /    55.6178 /    4.47806
hippo-L                                   :    5 /       2548 /       2548 /    52.6429 /    4.15063
vent-temp                                 :    6 /       1047 /       1047 /    23.5244 /    7.34334
caudates                                  :    7 /       7661 /       7661 /    56.3759 /    3.92178
corpus-callosum                           :    8 /      16841 /      16841 /    69.2177 /    6.05497
~
                                                                                      1,1           All
```

Hands-on Exercise (20 minutes)

1. Load image in the DICOM directory
2. Correct image orientation
3. Set contrast automatically
4. Create labels for left lung, right lung and tumor
5. Use polygon tool to trace left and right lungs. Use the scaffolding technique
6. Use paintbrush tool to touch up your lung segmentations
7. Use the adaptive paintbrush to segment the tumor
8. Save volumes and statistics

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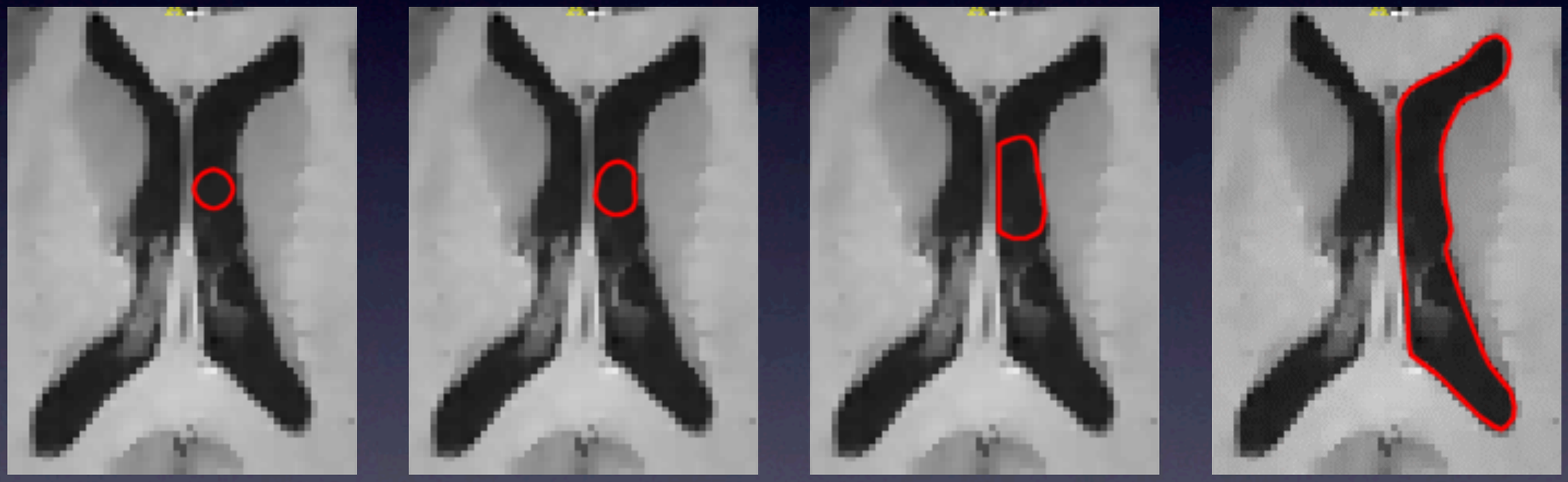
Module 4: Automatic Segmentation

- Theory of active contour segmentation
- Automatic segmentation demos

Automatic Segmentation

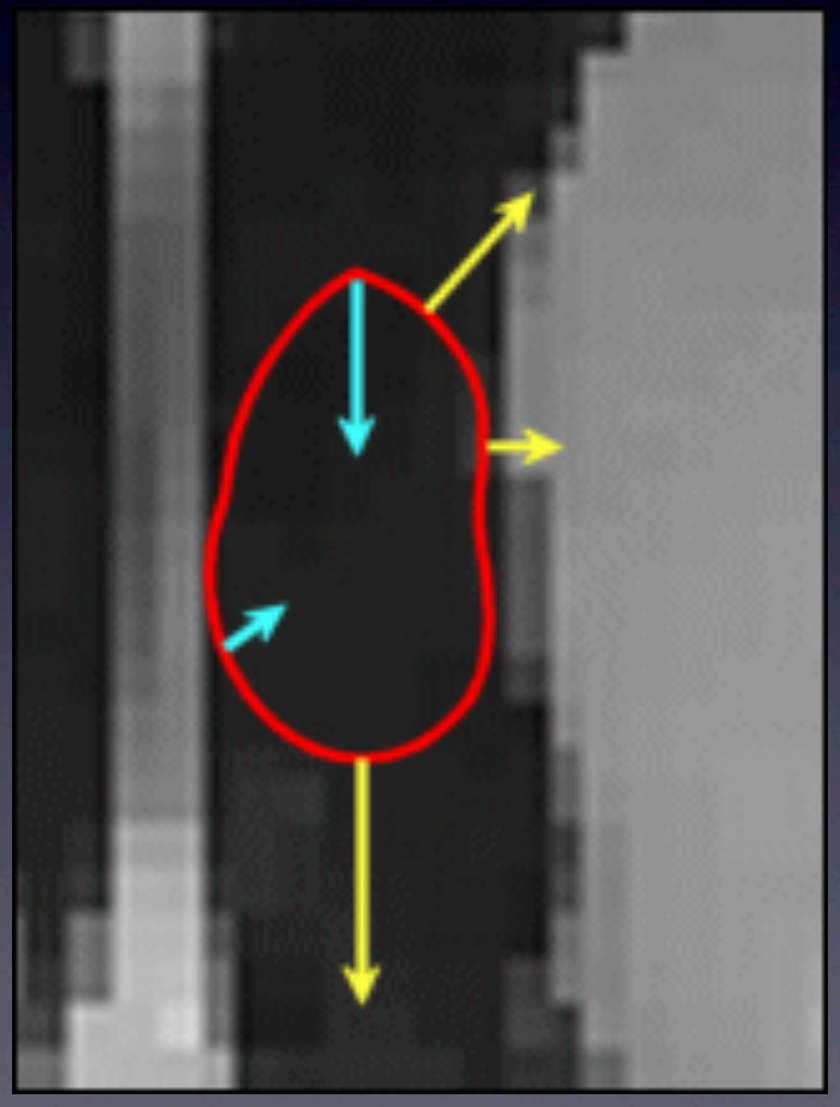
- Rule #1: Garbage In = Garbage Out
- Automatic segmentation is weaker than manual segmentation, but it saves you time

Active Contour Evolution



Active Contour is Controlled by Forces

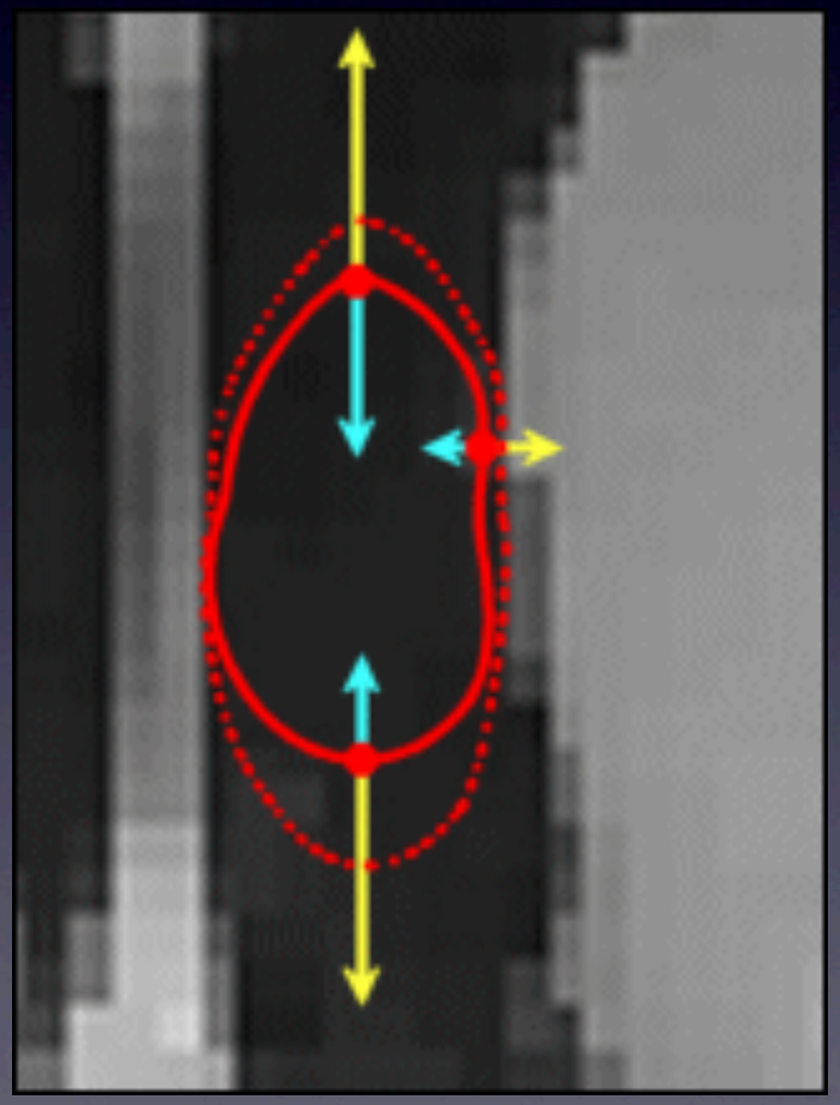
Image-driven force pushes the contour towards the boundaries of the object of interest



Shape-driven force pushes the contour towards maintaining a simple shape

Active Contour is Controlled by Forces

Image-driven force
pushes the contour towards the boundaries of the object of interest



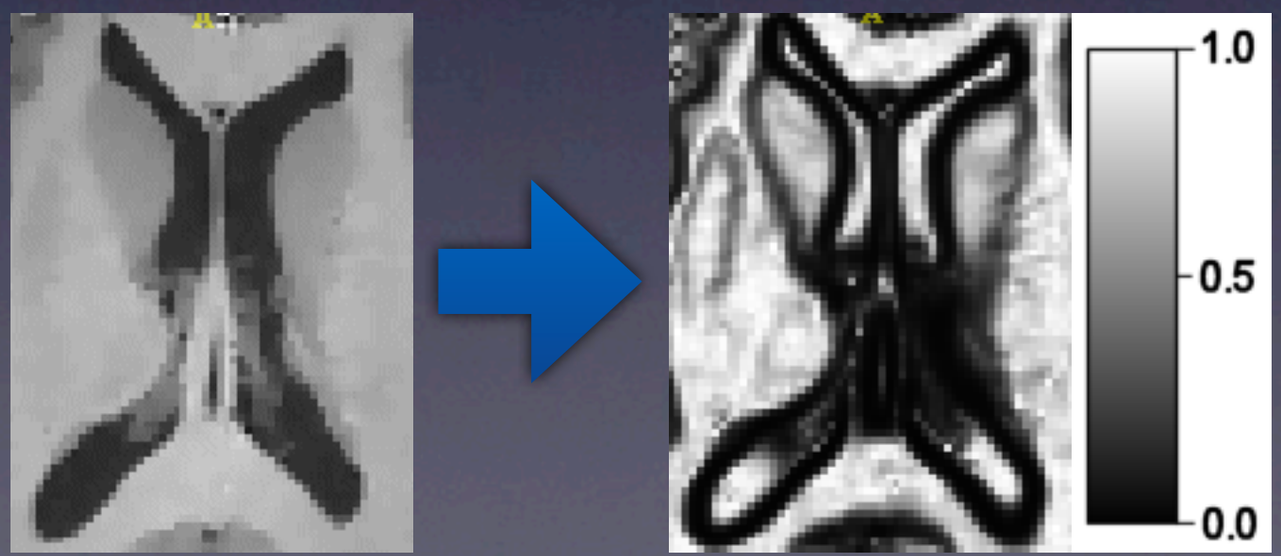
Shape-driven force
pushes the contour towards maintaining a simple shape

Forces

- Forces act perpendicular to the contour
- Shape force is proportional to the curvature of the contour

Forces

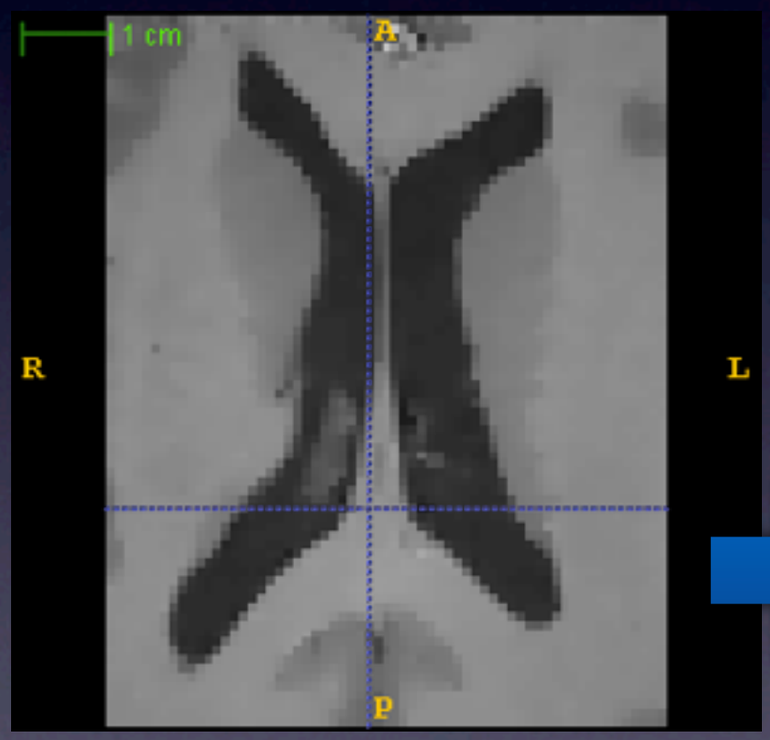
- Image force is proportional to the value of the **speed image** under the contour
- Speed image is derived from the grayscale image in various ways

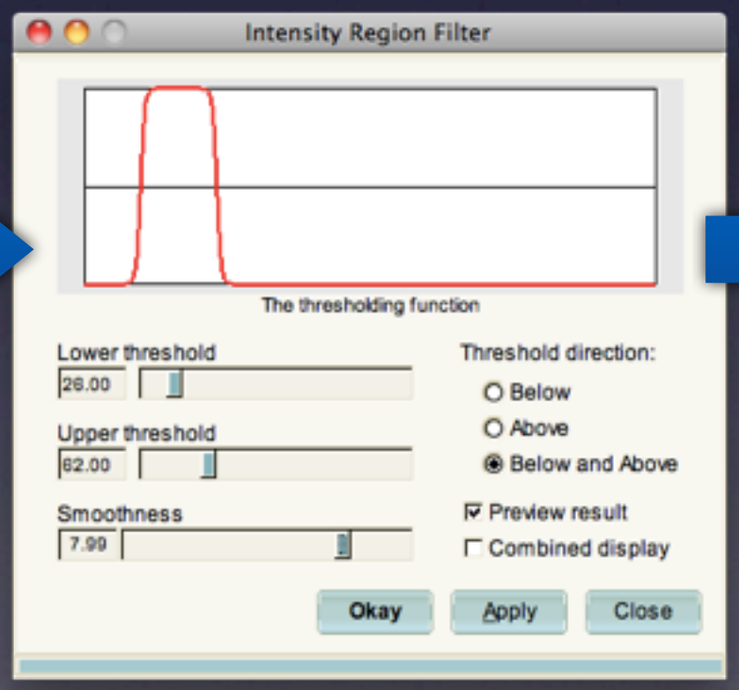


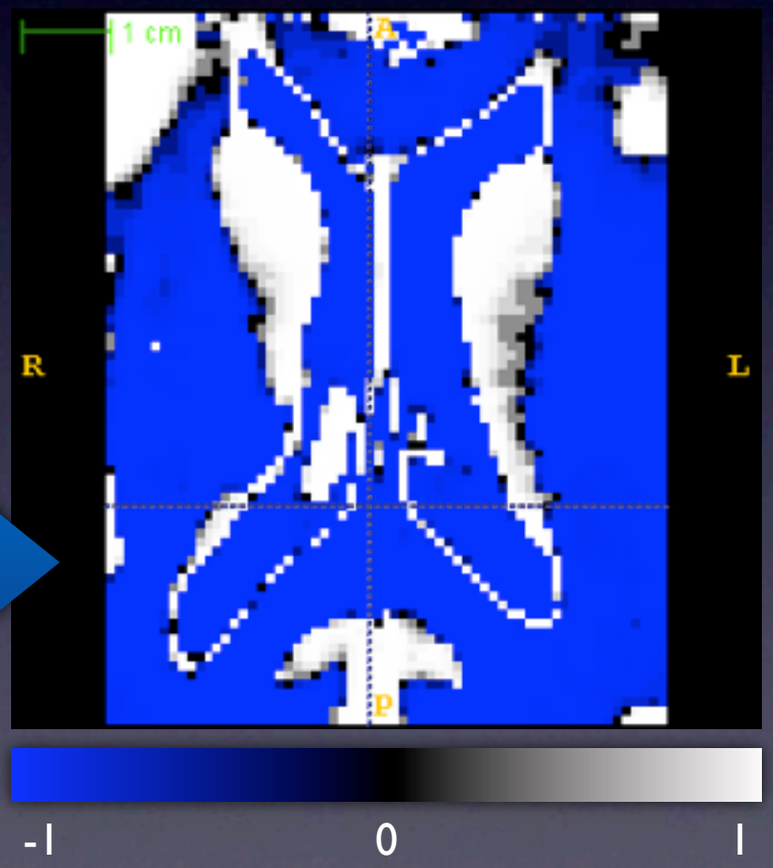
Region-Based vs. Edge-Based Speed Functions

- Region-based:
  - Objects of interest have roughly uniform intensity values
- Edge-based:
  - Objects of interest are separated from other objects in the image by **edges**, i.e., strong discontinuities in intensity

Region-Based Speed Function







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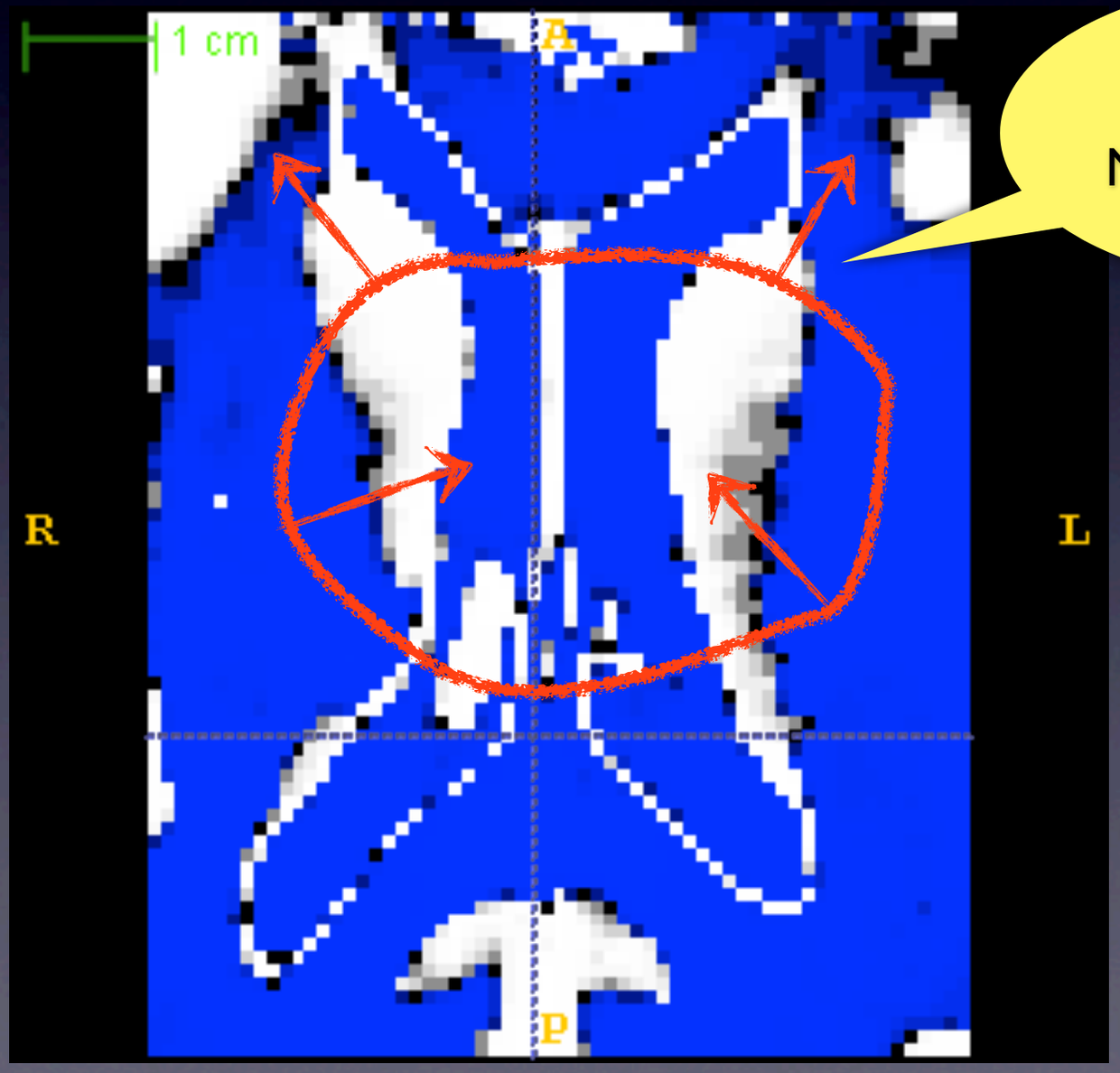
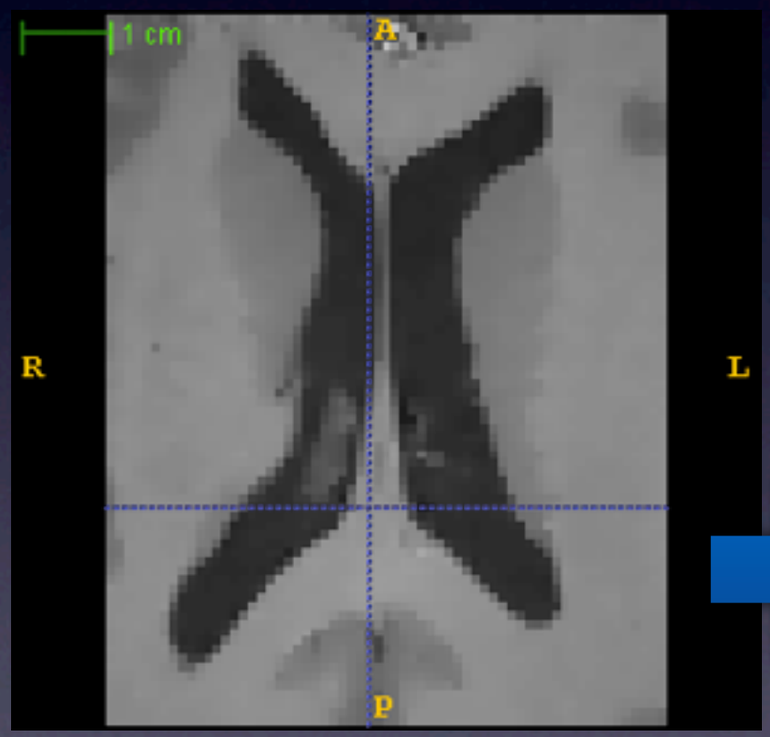
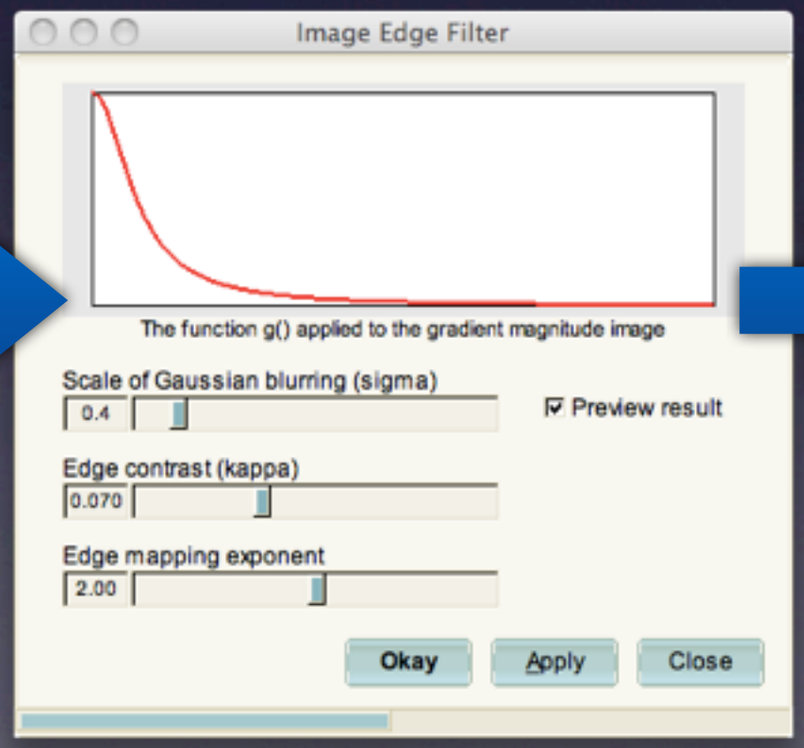
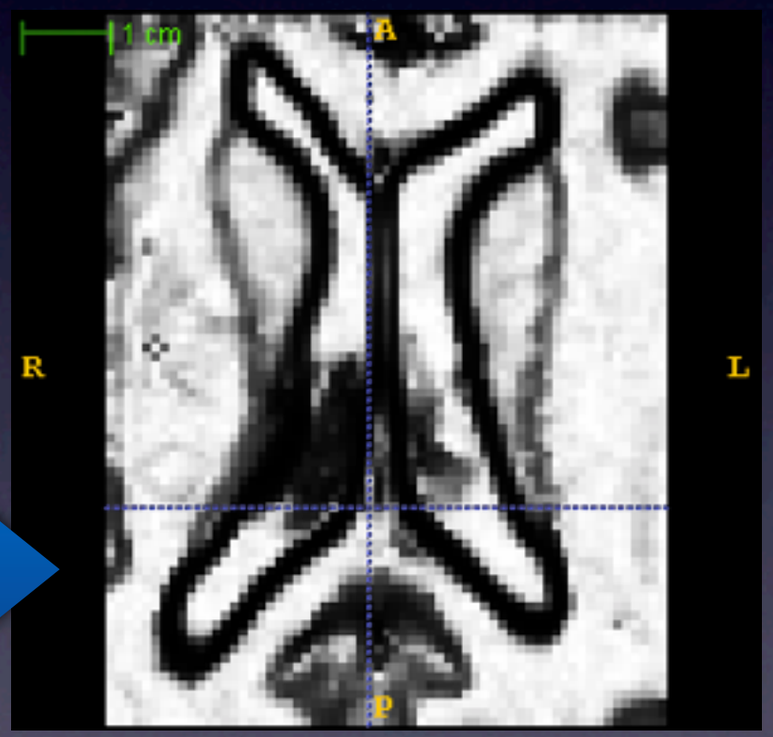


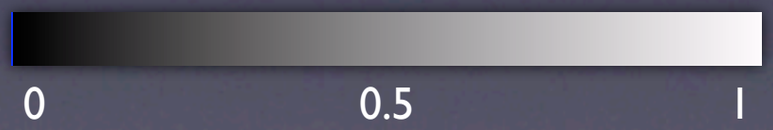
Positive: expand
Negative: contract

Edge-Based Speed Function









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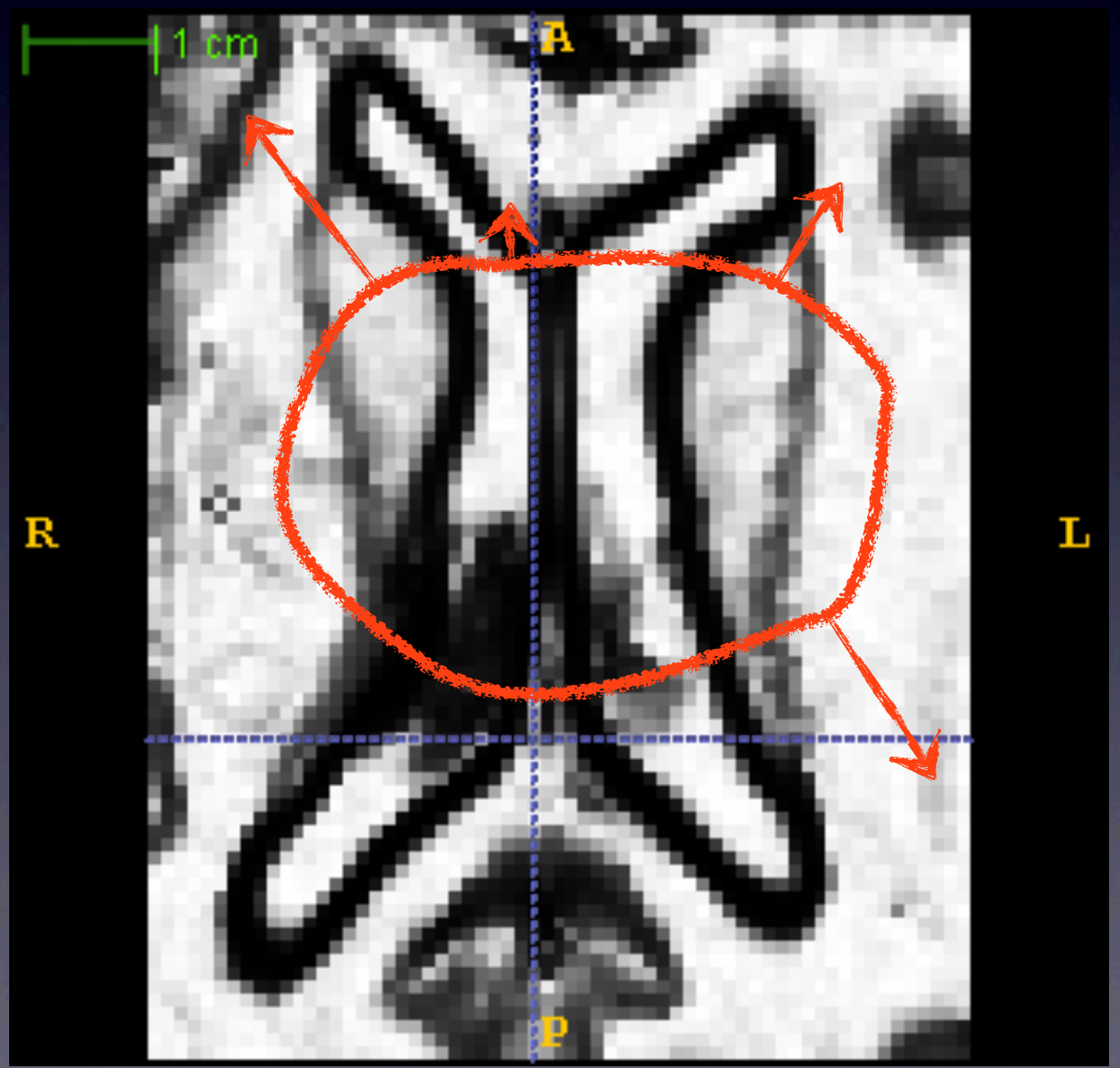
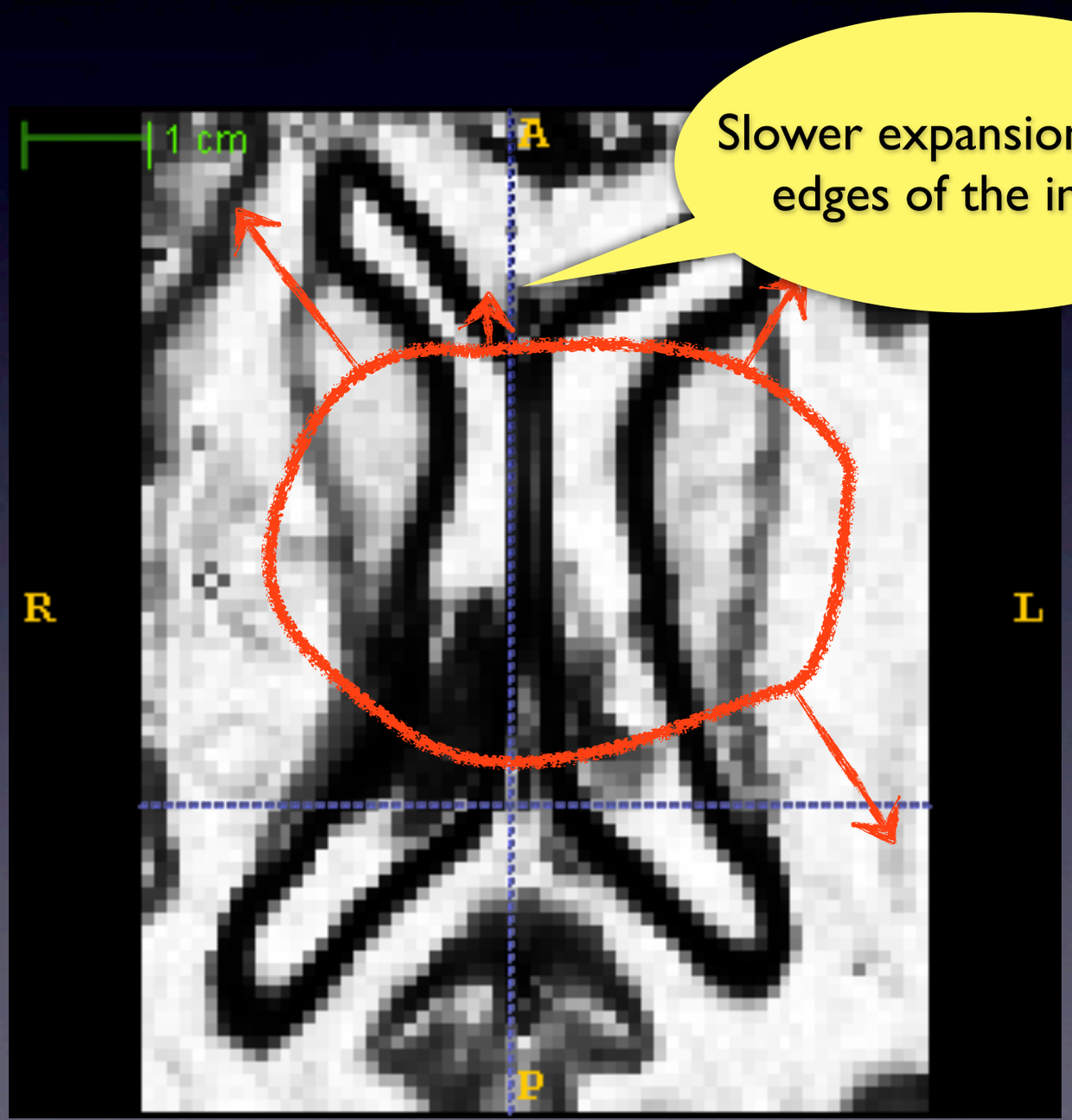
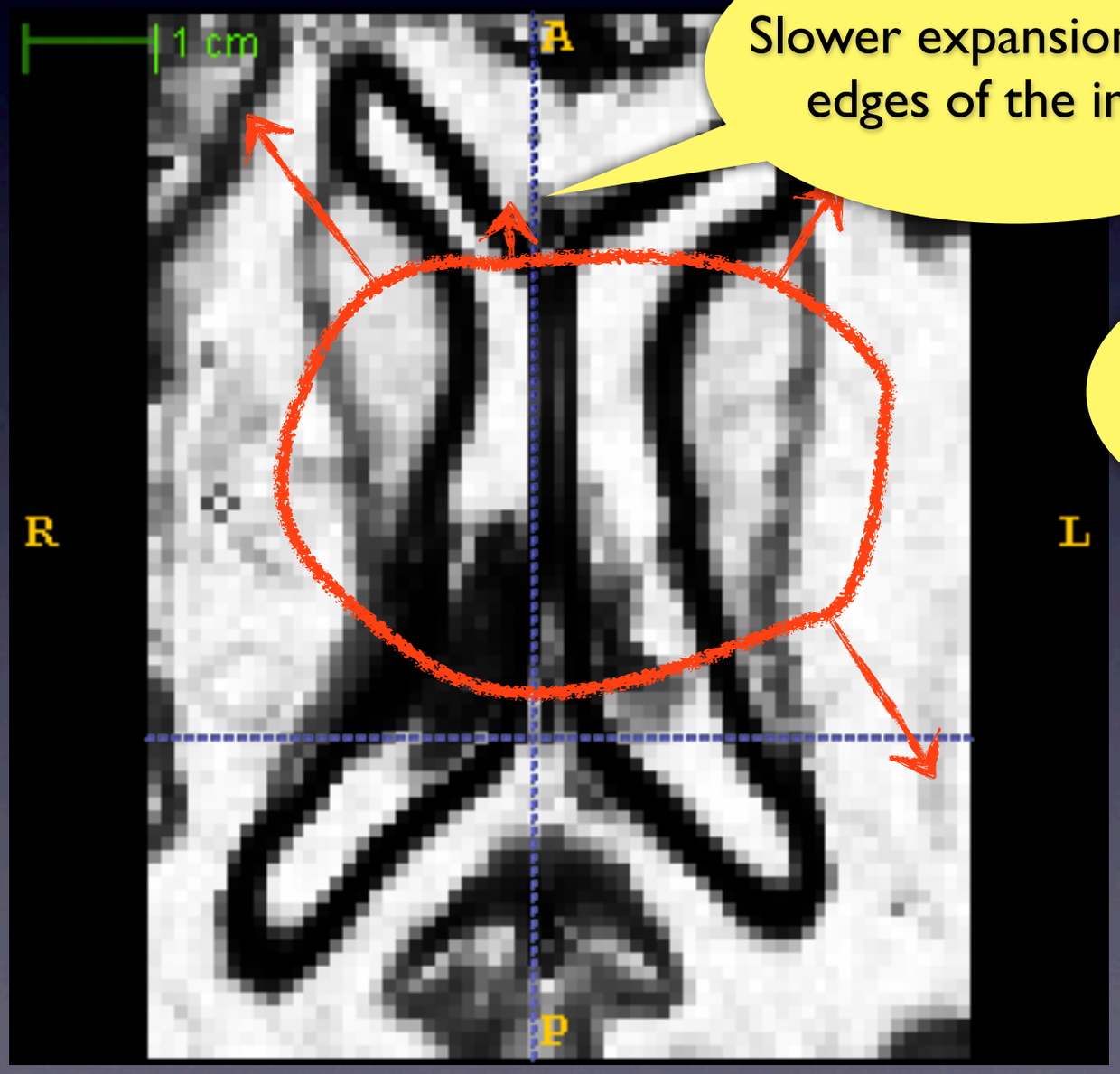


Edge-Based Speed Function



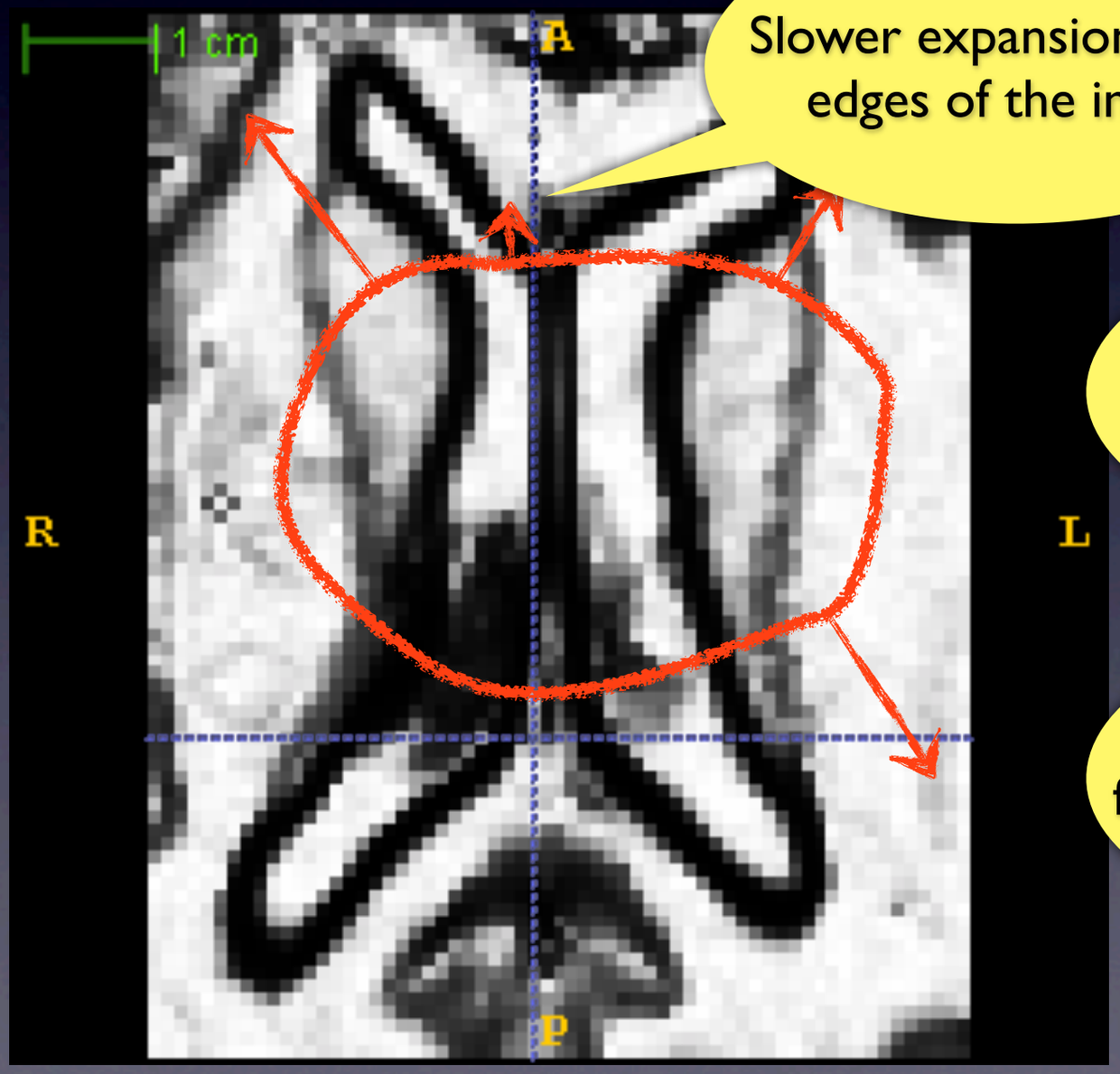
Edge-Based Speed Function



Slower expansion at the edges of the image

Edge-based contour will "leak" past weak edges

Edge-Based Speed Function



Slower expansion at the edges of the image

Edge-based contour will "leak" past weak edges

Use additional "advection" force to push back on the contour at edges

Level Set Method

- Contour is represented by a 3D image
- |intensity| at a voxel = distance to contour
  - positive = outside contour; negative = inside
- This “implicit” representation of the contour improves numerical stability

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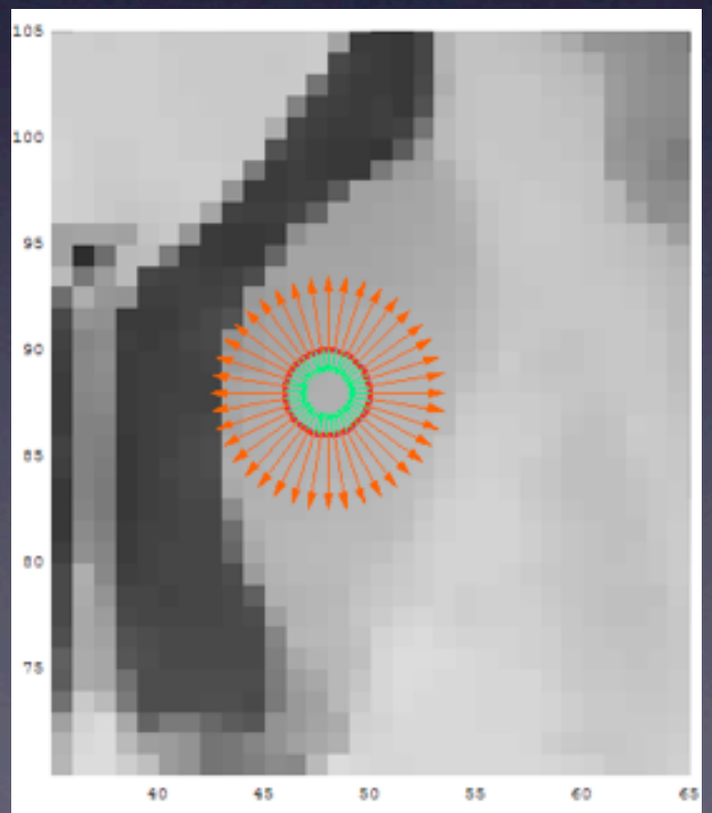

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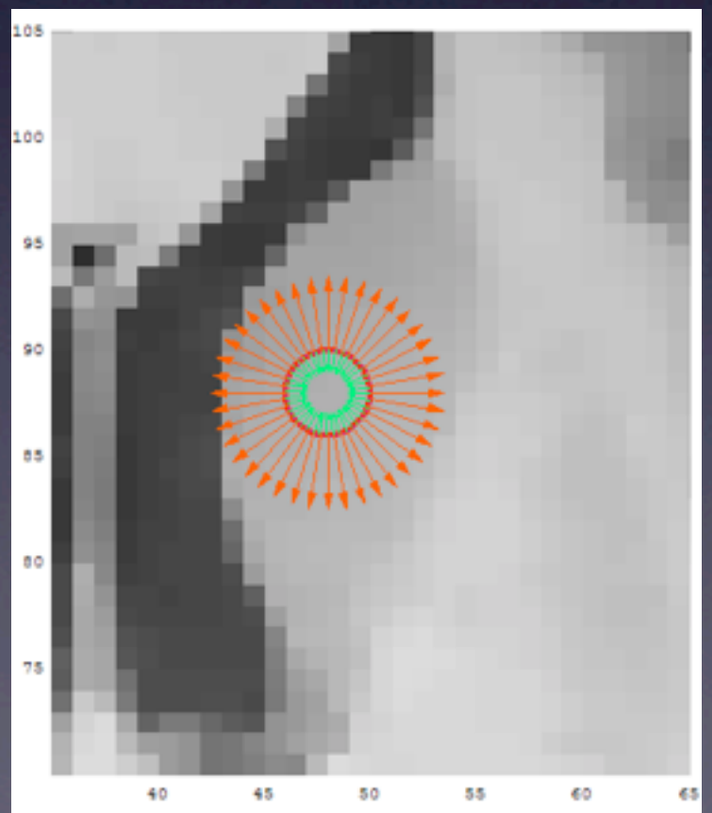
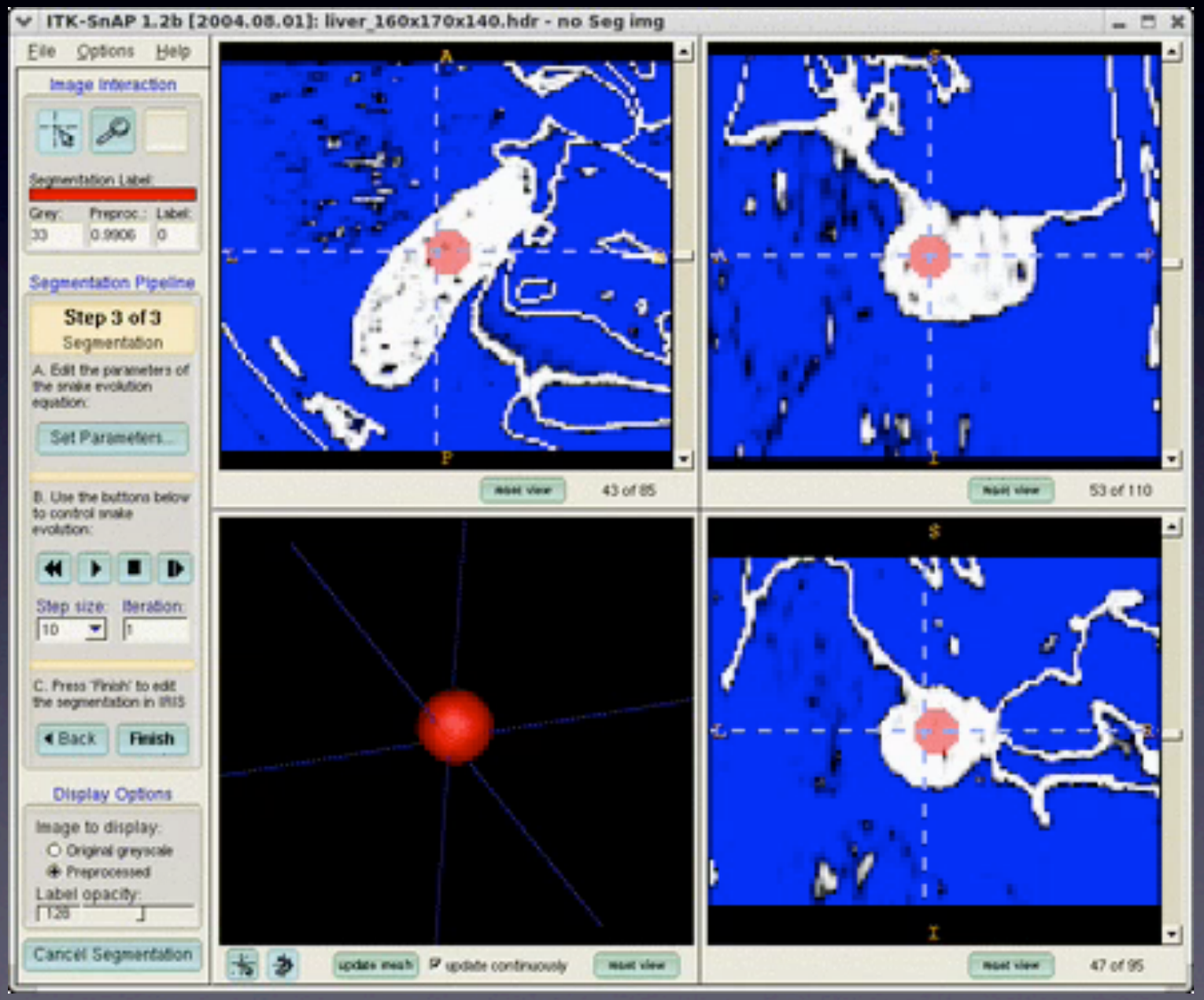


Active Contour Segmentation

- Step 1: set up the speed function
- Step 2: place initial contour(s)
- Step 3: watch contour evolve

Segmentation Example



GUI Demo: Automatic Segmentation

Hands-on Exercise (20 minutes)

1. Load image mouse_brain_t1_region_bc.nii
2. Define bounding box around the ventricles
3. Segment the ventricles using region-based method
4. Use 3D cut plane tool to label left/right ventricles
5. Use manual tools to touch up your segmentation
6. Report the volumes of the ventricles
7. Segment left hippocampus using region-based method
8. Use 3D tools to remove gray matter adjacent to it

Course Modules

- Module 1: Introduction
- Module 2: Image Viewing and Navigation
- Module 3: Manual Segmentation
- Module 4: Automatic Segmentation
- Module 5: Advanced Topics

Module 5

- Changing appearance preferences
- Generating figures for publication
- Overlays and color maps
- Multiple SNAP sessions

GUI Demo:
Advanced Features

What's Left?

- Lot more to learn about SNAP
  - Check out documentation, mailing lists
- Power users might like
  - SNAP command-line options
  - Convert3D - SNAP's versatile companion

Bugs, etc.

- SNAP has some bugs. Sorry!
- Often it's the graphics card. Or too little memory. Try another machine.
- Please report bugs. Give as many details as you can. Otherwise, we can't fix them.

Thank you and enjoy!